CHAPTER 6
MODELING

This chapter describes various modeling techniques applicable to the airworthiness qualification process. Section I discusses physical models used to represent system characteristics of interest including aerodynamic models, inert physical mock-ups, functional subsystem mock-ups, and ground test vehicles. Section II addresses simulations, including simulation bases, emulators, simulators, and simulations, as software environments.

SECTION I
PHYSICAL MODELS

6-0 LIST OF SYMBOLS

D = characteristic length, m (ft)
R_n = Reynolds number, dimensionless
v = air velocity, m/s (ft/s)
μ = absolute viscosity, Pa·s (lbf·s/ft^2)
ρ = air density, kg/m^3 (slug/ft^3)

6-1 INTRODUCTION

Models and mock-ups are used extensively during air vehicle design and development. Scale models are generally used early in the design to investigate aerodynamic effects and interactions using wind tunnels and flow tanks. Results of scale model testing provide the designer insights into the aerodynamic characteristics of the air vehicle being developed. The data obtained from models may be used to predict flight limitations, performance, and handling quality characteristics. For example, a powered force model (PFM) could be used to determine whether the horizontal stabilizer design is adequate to provide positive longitudinal stability.

At an early stage in the development cycle, a full-scale air vehicle mock-up or computer-aided engineering substitute should be fabricated to function as a design tool to determine the optimum air vehicle configuration. Computer-aided substitutes are capable of a degree of functional realism that is comparable to a physical mock-up.

This mock-up should be capable of demonstrating the compatibility of the ground handling, maintaining, loading, and operating requirements of the air vehicle and its equipment. Particular regard should be given to crew and passenger stations, cargo and weapon provisions, equipment arrangement, and propulsion system installations. Visibility for the flight crew, lighting, effective clearances, and personnel safety also should be considered. Individual subsidiary mock-ups may be required for specific areas such as crew stations and lighting. Also functional mock-ups should be fabricated for most subsystems.

The full-scale mock-up may be used to assist in packaging and in arrangement tradeoff studies for selected components. Such a mock-up offers a three-dimensional presentation for other engineering disciplines, such as maintainability, reliability, producibility, and system safety, to evaluate and plan subsequent test demonstrations. Mock-ups are routinely used as design tools to establish effective arrangements or to resolve subsystem interface problems as they affect form, fit, and function.

6-2 AERODYNAMIC MODELS

Aerodynamic models are scale models intended to allow investigation of the interactions between the air vehicle or air vehicle section and the fluid (air) through which it travels. Aerodynamic models should conform to the shape of the actual object being modeled. These scale models are important for flight limit investigations because they give designers an early insight into the aerodynamic characteristics of the air vehicle long before full-scale hardware is built. Deficiencies found through this early investigative work can be corrected with much less effort than if discovered later in the development. This paragraph describes airfoils and two-dimensional aerodynamic shapes, flow tanks, wind tunnels, force models, powered force models, and icing tunnels and icing mock-ups. Fig. 6-1 provides a pictorial example of each of these types of models.
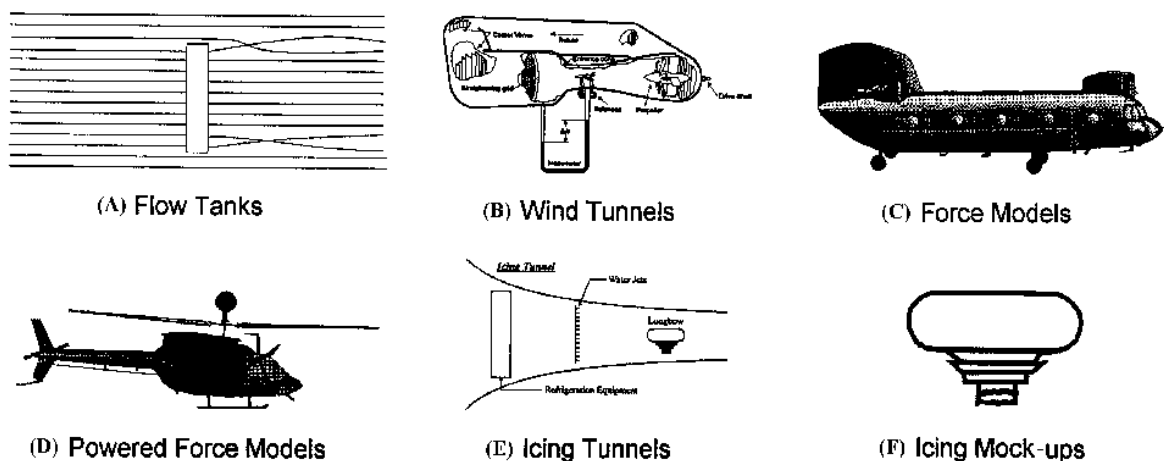

(A) Flow Tanks   (B) Wind Tunnels   (C) Force Models

(D) Powered Force Models   (E) Icing Tunnels   (F) Icing Mock-ups

Figure 6-1. Aerodynamic System and Environment Models

6-2.1 AIRFOILS AND TWO-DIMENSIONAL AERODYNAMIC SHAPES

An airfoil or aerodynamic shape is a structure, piece, or body designed to obtain a useful reaction upon itself in its motion through the air. Airfoil and two-dimensional aerodynamic shapes are used to determine the aerodynamic characteristics of a particular shape, namely, the drag coefficient, the lift coefficient, and the moment coefficient for an infinite aspect ratio. These coefficients are functions of the angle of attack of the airfoil section. From these coefficients the lift, drag, and moment generated by an airfoil may be determined and used to make early predictions of performance characteristics.

6-2.2 FLOW TANKS

Flow tanks (usually water tanks) are used to provide a visualization of the aerodynamic flow about an object. They consist of a chamber, a means (pump) of producing a fluid flow around the object being modeled, and a means of seeding the fluid flow with a visible tracer, such as smoke or dye. In most cases the tracer is introduced upstream of the object being tested and thus set up a series of parallel streams in the fluid flow. The tracer may also be introduced in the flow stream through holes in the aerodynamic model. As the fluid flows around the model, these parallel streams become disturbed by the object, and this disturbance provides a visualization of

the flow around the object. When properly scaled for fluid differences, flow tanks can be used to visualize the airflow around the object. They can also be used to visualize the airflow aerodynamics of wingtip vortices around a wing and flow about the main rotor and tail rotor. These types of preflight data are useful for predicting flight characteristics, such as separation turbulence and interference, prior to actual flight experience. The objective is to detect any defect or design deficiency and to evaluate fixes.

6-2.3 WIND TUNNELS

Wind tunnels provide a means of simulating air vehicle flight by moving air over a stationary scale model of the air vehicle. This allows the measurement of aerodynamic data and evaluation of aerodynamic design. The tunnel typically consists of a large closed circuit tube. The tube contains a propeller (usually shaft driven), which creates the flow of air. Corner vanes minimize turbulence where the airflow must turn a corner. The chamber in which the model is mounted (the throat) has a reduced cross-sectional area and corresponds to the throat of a venturi; thus a local increase in air velocity is created. The model is mounted on scales or other force measurement devices. Wind tunnel facilities often have unique characteristics that require testing to be performed at specific sites. Principal characteristics that affect tunnel results are air density, pressure at the throat, free-stream pressure, cross-sectional area atthe throat, and cross-sectional area at the settling chamber. The critical parameter that must be matched between the model situation and the actual physical (full-scale) conditions of flight is the dimensionless Reynolds number R_n, which is defined as

$$R_n = \frac{Dv\rho}{\mu}, \text{dimensionless} \quad (6\text{-}1)$$

where
R_n = Reynolds number, dimensionless
D = characteristic length, m (ft)
v = air velocity, m/s (ft/s)
ρ = air density, kg/m^3 $(slug/ft^3)$
μ = absolute viscosity, Pa·s $(lbf·s/ft^2)$.

Matching Reynolds numbers is no guarantee of perfect similarity; however, since the wind tunnel conditions are not completely uniform and include wall effects not encountered in the free air, model and actual air vehicle matching is seldom achieved. Examples of measured parameters obtainable from wind tunnel testing include lift and drag characteristics, flow pressures and separation characteristics over control surfaces, and general pressure/velocity distributions. Tunnel characteristics that could affect results must be considered during test design. Examples of typical tunnel characteristics that should be considered include test section size, maximum velocity capability, inherent tunnel turbulence, and temperature/humidity control. Some of these facility-dependent characteristics enable valid measurements only at specific facilities. Table 6-1 lists several major facilities and their capabilities. Additional information on wind tunnel

TABLE 6-1. WIND TUNNELS

FACILITY	TEST SECTION, m (ft)	MAXIMUM VELOCITY, m/s (mi/h)	SPECIAL CAPABILITY
NASA Ames Moffett Field, CA	12.2 ´ 24.4 (40 ´ 80)	116 (260)	Full-scale, high-speed
NASA Ames Moffett Field, CA	12.2 ´ 36.6 (40 ´ 120)	39 (87)	Full-scale, low-speed
NASA Langley 16-ft Transonic Langley, VA	4.9 ´ 4.9 (16 ´ 16)	0.7 to 1.2 Mach	Transonic flow
NASA Langley LAL 20-ft Spin Langley, VA	6.1 (20) 12-sided polygon	23 (52)	Spin testing
Boeing Research Wind Tunnel Seattle, WA	1.5 ´ 2.4 (5 ´ 8)	58 (130)	Low turbulence
Boeing BVWT Philadelphia, PA	6.1 ´ 6.1 (20 ´ 20)	97 (217)	VSTOL
WP 10- ´ 7-ft Wright-Patterson AFB, OH	3.0 ´ 2.1 (10 ´ 7)	156 (348)	High-speed, low-turbulence flow visualization
DTNSRDC Anechoic Carderock, MD	24. ´ 2.4 (8 ´ 8)	52 (117)	Sound studies
University of Notre Dame, Notre Dame, IN	0.6 ´ 0.6 (2 ´ 2)	24 (53)	Smoke tunnels

locations and capabilities may be obtained from Ref. 1. The aerodynamic data collected from wind tunnel tests provide another significant building block in the substantiation of qualification characteristics by providing essential aerodynamic information. With the advancing capabilities of computational fluid dynamics (CFD), it appears possible to reduce the amount of wind tunnel test time required for future development programs.

6-2.4 FORCE MODELS

Reduced-scale air vehicles and three-dimensional sections, such as wings and fuselage, are the types of physical models subjected to wind tunnel testing. The types of aerodynamic data that can be validly measured from these models include lift, drag, and moment characteristics. Precautions are required in mounting the model and conducting the test so the results of the test are not affected. Examples of these precautions are ensure the natural frequency and structural strength of the mount are adequate for the intended purposes, ensure proper calibration of balances, and ensure proper use of available correction factors, ensure model is properly sized to avoid excessive air blockage. The measured aerodynamic data form a basis for flight simulation and subsequent qualification.

6-2.5 POWERED FORCE MODELS

Powered force models are reduced-scale models that include powered rotors, control surfaces, and other moving parts. These models often are 15 to 30% scale and/or dynamically similar models of the air vehicle. With these models, rotor/body, rotor/rotor, and rotor/tail mutual aerodynamic interference effects can be investigated. With dynamically scaled models, aeroelastic stability problems can be determined and investigated early in the acquisition process. The special

types of data that can be measured from these models include air inlet and exhaust area pressures at all flight attitudes and velocities, flow pressures and separation characteristics over control surfaces, and weapon exhaust gas flow.

6-2.5.1 Aerointerference Models

Aerointerference models are used to determine the aerodynamic impact of one aerodynamic surface on another. Examples include the impact of main rotors o n tail rotors and the impact of wings on tail surfaces. Aerointerference models may be force models or powered force models and thus require the same types of pr ecautions to ensure accurate data.   Further, more elaborate i nstrumentation to measure aero-interferences may require special precautions to prevent distortion of the test results   by instrumentation intrusion in critical airflow areas.

6-2.5.2 Aeroelastic Models

Aeroelastic models are used to determine the interactions of aerodynamic forces, elastic forces, and inertial forces in order to establish the aerodynamic characteristics of air vehicles. Aeroelastic models are used for dynamic stability tests to investigate dynamic behavior dominated by rigid body modes of motion and during flutter tests to investigate dynamic instabilities caused by the elasticity of the structure.   Aeroelastic models are generally excited during dynamic stability tests and flutter tests through the use of jerk wires that permit a rapid change in attitude and/or oscillations in attitude of the model relative to the airstream. Just as in the case of wind tunnel testing, a dimensional analysis must be performed for the aeroelastic model to determine the critical parameters linking the real world and the model . Factors entering into aeroelastic model similarity include mass, frequency, length, modulus of elasticity, and area moment of inertia. As airloads and flutter enter the model considerations, the complexity   of the dimensional analysis grows.

6-2.6 ICING TUNNELS AND ICING MOCK-UPS

Icing tunnel tests allow evaluation of systems under icing conditions and permit optimization of the design prior to flight. Icing conditions can be simulated in the tunnel at the desired flight or ground operating conditions . During these tests, electrical power density, hot airflow, hot air temper ature requirements, bleed air requirements, and anti-icing fluid requirements for ice protection of various aero dynamic shapes, such as airfoils, air induction systems, and windshields

Test conditions on air vehicle engine air induction systems should reflect the   downwash characteristics and effects obtainable with the particular air vehicle configuration. Tests on components (in the laboratory or in flight) are conducted over the full spectrum of icing condition parameters (particularly temperature and liquid water content) to ensure that (1) engine performance requirements are met, (2) downwash impingement does not introduce special problems, and (3) no hot spots exist that could cause system failure. Cold spots that may permit ice accretions, which detach and cause engine damage, also are evaluated.

Generally, an acceptance test duration of 30 min with full performance compliance is required at each condition. To minimize the possibility of damage, preliminary, short-duration tests usually are conducted to perform visual checkout prior to the acceptance test.

Heat transfer characteristics of the windshield or canopy can be established at simulated flight conditions. Complete systems can be evaluated, and windshield wiping, washing, and defogging operations can be developed or demonstrated in the icing tunnel. Tests are conducted to evaluate whether or not visibility requirements across the airspeed and icing spectrum are met. In addition, tunnel tests can identify hot spots that can result from airflow stagnation and cause system failure. Table 6-2 provides a list of icing test facilities and their capabilities.

6-3 INERT PHYSICAL MOCK-UPS

Inert physical mock-ups include general reduced-scale models; fuselage mock-ups; flight crew stations mock-ups; and mission crew, passenger, and cargo area mock-ups. These models may be constructed from substitute materials, black boxes may be empty, and equipment shells or housing may be used. In addition, computer-aided engineering may be used to assess the physical interrelationships among system components. The impacts of layout on design evaluation and qualification include accessibility (for maintainability considerations), human factors, and entry and exit considerations. Fig. 6-2 shows typical physical models. Additional information for the construction of air vehicle and related system mock-ups for formal evaluation is contained in MIL-M-8650, *Mock-Ups, Aircraft, General Specification for*, (Ref. 2).

6-3.1 GENERAL REDUCED-SCALE MODEL

A general reduced-scale model is a system model built to a reduced scale for use as an adjunct to general arrangement drawings. It facilitates the visualization of the physical arrangements and allows for early detection and correction of physical interference problems. In addition, it functions as a three-dimensional visual aid to assess general compartment arrangement, access, space and shape, and payload potential layout. In addition, the reduced-scale model can be used with other models and layouts to demonstrate its air and sea transportability. It provides an early answer to the question, "How does everything fit together?".
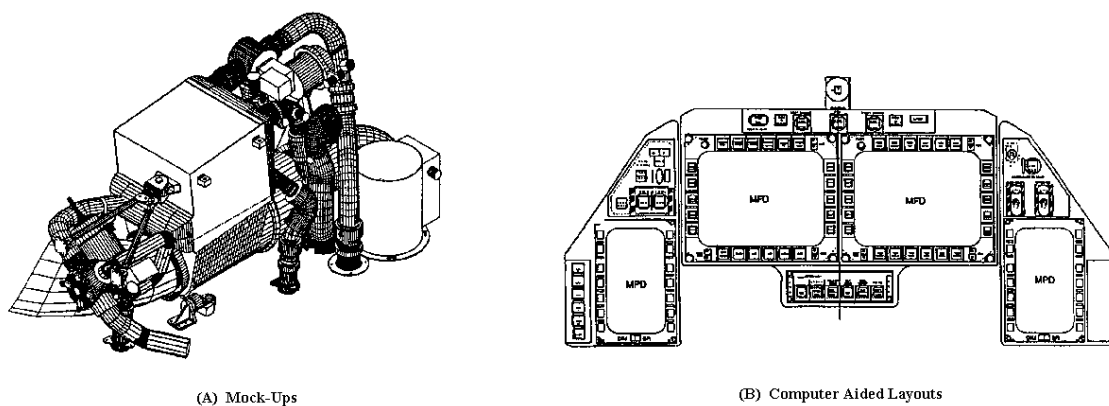

(A) Mock-Ups   (B) Computer Aided Layouts

Figure 6-2. Inert Physical Models

TABLE 6-2. ICING TEST FACILITIES

FACILITY	SIZE, m (ft)	SPEED	MINIMUM TEMPERATURE, °C (°F)	LIQUID WATER CONTENT, g/m³	DROPLET SIZE, μ m (μ in.)	TYPE*
NASA Lewis Research Center Cleveland, OH	1.83 × 2.74 (6 × 9)	0-240 kt	−28.9 (−20)	0 to 2	10 to 30 (394 to 1181)	1
Naval Air Propulsion Test Center Trenton, NJ	7.01 × 7.01 (23 × 23)	0 to Mach 0.9	−20 (−4)	1 to 2	15 to 25 (591 to 984)	1
Naval Air Propulsion Test Center Trenton, NJ	5.18 (17) diameter	0 to Mach 2.4	−20 (−4)	1 to 2	15 to 25 (591 to 984)	1
Naval Air Propulsion Test Center Trenton, NJ	4.42 (14.5) diameter	0 to Mach 2.4	−20 (−4)	1 to 2	15 to 25 (591 to 984)	1
Naval Air Propulsion Test Center Philadelphia, PA	0.61 (2) diameter	70 to 75 mph	−30 (−22)	0.1 to 3	15 to 50 (591 to 1968)	1
Lockheed, California Burbank, CA	0.76 × 1.22 (2.5 × 4.0)	50 to 186 kt	−21 (−5)	0.7 to 4	7 to 35 (276 to 1378)	1
Lockheed, CA Burbank, CA	0.76 × 0.76 (2.5 × 2.5)	50 to 210 kt	−18.9 (−2)	0.7 to 4	7 to 35 (276 to 1378)	1
The Boeing Company Seattle, WA	4.57 × 6.10 (15 × 20)	0 to 200 kt	−34.4 (−30)	down to 5	15 to 25 (591 to 984)	1
National Research Council of Ottawa Ontario, Canada	0.30 × 0.30 (1 × 1)	0 to Mach 0.9	−40 (−40)	0 to 3	15 to 60 (591 to 2362)	1
National Research Council of Ottawa Ontario, Canada	1.37 ×1.37 (4.5 × 4.5)	0 to 200 mph	−25 (−13)	0 to 3	15 to 60 (591 to 2362)	1
National Research Council of Ottawa Ontario, Canada	1.56 × 2.44 (5 × 8)	0 to 500 mph	−25 (−13)	0 to 3	30 to 60 (1181 to 2362)	1
National Research Council of Ottawa Ontario, Canada	16.75 × 3.05 (55 × 10)	hover	ambient	0 to 0.9	30 to 60 (1181 to 2362)	2
Eglin Air Force Base, FL	9.14 × 9.14 (30 × 30)	0	17.8 (0)	0.5 to 20	15 to 90 (591 to 3543)	4
C-130 Tanker, Wright-Patterson Air Force Base Dayton, OH	N/A	up to 150 kt	ambient	0.1 to 1.1	80 to 100 (3150 to 3937)	3
KC-135 Tanker, Wright-Patterson Air Force Base Dayton, OH	N/A	up to 500 kt	ambient	0.1 to 1.1	80 to 100 (3150 to 3937)	3
US Army Helicopter Icing Spray System (HISS), CH-47 Edwards Air Force Base, CA	N/A	up to 120 kt	ambient	0.1 to 1.1	80 to 100 (3150 to 3937)	3

*1 = icing tunnels and engine icing chambers
2 = natural icing spray rig
3 = tanker aircraft
4 = climatic hangar and icing spray rig

6-3.2 FUSELAGE MOCK-UP

The internal and external shape and size of the air vehicle mock-up duplicates the dimensions of the engineering design to permit assessment of general configuration suitability for loading and unloading of crew, troops, cargo, weapons, ammunition, and fuel; for vision obscurations; for performance of crew functions; and for postcrash escape. The maintainability features of the air vehicle with respect to component accessibility, adequacy of built-in work platforms, and ground crew requirements to perform scheduled and unscheduled maintenance can be demonstrated.

Other design features that can be demonstrated on the mock-up include accessibility to doors, the cargo compartment, and fueling locations. The operation of doors, windows, hatches, emergency exits, controls, and functional equipment such as retractable landing gear or retractable steps can also be demonstrated.

The mock-up is configured to allow actual installation of any equipment that will alter its exterior shape or size. Control surfaces, turrets, flexibly mounted equipment hoists, external auxiliary fuel stores, weapon racks, and battlefield illumination devices should be capable of traversing their full range of movement to allow for demonstration of clearance limits, weapon fire angle limits, and weapon handling clearance limits.

The mock-up incorporates all of the steps, ladders, handholds, access hatches, and work platforms defined in the air vehicle design. Environmental devices, such as windshield wipers and deicer boots, which may affect the external configuration of the air vehicle, are also part of the mock-up.

The fuselage mock-up includes the crew stations, passenger and/or cargo compartments, and equipment compartments. Doors, hatches, windows, escape areas, access ways, handgrips, steps, tie-down provisions, and jacking provisions are mocked up. The fuselage mock-up may be used to determine routing of items such as cables and lines. Access points for maintenance and repair of air vehicle equipment should be included in the mock-up.

The size and location of escape hatches and emergency provisions for crew and passengers can be mocked up. Photographs and motion films of a simulated emergency evacuation may be provided for a slow-speed evaluation of potential hazards to the occupants from controls, equipment, or structure. The mock-up should be flexible enough to allow evaluation of proposed and/or alternate installations prior to building the air vehicle.

6-3.3 CREW STATIONS

Crew station modeling includes flight crew station mock-up and the modular reconfigurable flight crew station simulator. These are used to determine the acceptability of the design with respect to provisions necessary to perform the mission. The mission crew station and the passenger and cargo areas are described in subpar. 6-3.4.

6-3.3.1 Crew Station Mock-Up

Cockpit(s) should include flight controls, propulsion controls, controls for retractable landing gear, rotor brake controls, electrical consoles and controls, armament equipment and electronic controls, instruments and displays, navigation equipment, the oxygen subsystem, normal and emergency controls for canopy and/or door actuation (including jettisoning), and cockpit furnishings and equipment that includes mirrors, microphones, headphones, etc. Furnishings and equipment should duplicate the production articles as closely as possible in size,

shape, and location. Actual safety belts, shoulder harnesses, parachutes, emergency kits, life rafts, seat pads, and back pads should be installed, when applicable. The eye position, seat reference point, and measurement techniques related to vision, controls, and displacements designed for the crew should be identified. Flight controls should be operable through their normal envelope, although they need not operate their respective rotors or surfaces. Control friction devices should be mocked up, and stops installed to limit all control movements to those anticipated for the actual air vehicle. The neutral positions of the cyclic control should be simulated. Control locks, when applicable, and means for adjusting the directional control and brake pedals should be included in the mock-up. Cockpit canopies (including framing), hatches, windows, etc., should be mocked up in sufficient detail that the overall field of view from the cockpit is depicted accurately. Provisions should be made for evaluators and test observers to stand outside the mock-up on each side of the cockpit on removable platforms and walkways.

To the extent possible, transparencies provided within the mock-up should be within the optical quality limits established for the air vehicle. Radii of curvature, thickness of panels, and framing widths for windshields and other transparencies in the cockpit should simulate those of the actual air vehicle. Adverse weather and/or night vision aids should be mocked up. Individual paper, cardboard, plastic, or metal dials representing all required instruments should be mocked up. The individual dials and panels as a whole should be capable of easy relocation. Extra panels with dials that also can be relocated easily should be provided apart from the mock-up. All furnishings and equipment essential to performing crew station tasks should be available in the mock-up for demonstration purposes.

6-3.3.2 Modular Reconfigurable Crew Station Simulator

This simulator provides a modular and readily reconfigurable physical layout for the purpose of evaluating various configurations. Physical layout is the emphasis for use of this simulator. Operational mock-ups provide additional insight into the crew/crew station interfaces through the evaluation of accessibility, operability, and often, functionality. Aitoff's equal area projection vision plots defined in MIL-STD-850, *Aircrew Station Vision Requirements for Military Aircraft*, (Ref. 3) provide a method of depicting the crew member's vision around the air vehicle from the normal eye position. Crew station simulators provide the initial basis for the preparation of the Aitoff plots. Section II of this chapter discusses crew station simulation further.

6-3.4 MISSION CREW, PASSENGER AND CARGO AREA

The mission crew, passenger, and cargo area mock-ups could be constructed to provide a representation of the physical layout of those areas. However, a computer-aided engineering (CAE) system or virtual prototype might be a more cost-effective substitute. Whatever approach is used should provide the means by which to determine available space, loading methods, and ease of ingress and egress.

6-3.5 COMPUTER-AIDED ENGINEERING SUBSTITUTION FOR MOCK-UPS

Computer-aided engineering systems enable a three-dimensional, solid geometry computer representation of a system. It offers the advantage of rapidly changing the viewing angle so the visual representations of the layout may be easily assessed. In addition, design changes can also be evaluated rapidly. It is essential that the CAE system be part of the configuration management

system in order to represent the latest approved configuration. The present state of CAE systems allows a reduced need for physical mock-ups. CAE can be effectively used as a substitute for subsystem form and fit. Design information from CAE can be shared by all disciplines from conceptual design through production. Physical mock-ups may still be required when operational maintenance procedures have to be established and demonstrated or as otherwise determined during the design, development, and qualification process. Physical mock-ups are also used for functional subsystem mock-ups, which are discussed in par. 6-4.

6-4 FUNCTIONAL SUBSYSTEM MOCK-UPS

For the purpose of this handbook a functional subsystem mock-up is a dynamic test fixture or rig capable of performing bench-level development and preflight qualification testing. These mock-ups (test rigs) approximate many of the operational parameters, such as loads, temperatures, pressures, voltages, motions, and vibrations. This paragraph discusses the electrical system; pressure system; engine and drivetrain; rotor system; electronic system manager networks; targeting, fire control, armament and stores stations; landing gear; and lighting system mock-ups. Their use in the development, evaluation, and qualification process is that they are part of the incremental, step-by-step buildup of experience relative to the characteristics of the system. They provide substantiation of characteristics that are properties of the subsystem alone and can be used for subsystem integration verification. It is often necessary to include partial mock-up of structure and other interfacing system parts that represent critical limitations to overall system performance. Because of limitations on the functional subsystem mock-up, system integration verification and qualification of many subsystems can often be completed only on a ground test vehicle and during flight tests on the air vehicle. Additional information on mock-ups can be obtained in MIL-M-8650 (Ref. 2).

6-4.1 ELECTRICAL SYSTEM

The electrical system functional mock-up should be used for checking out electrical components, interfaces, software, and firmware and for conducting preliminary electromagnetic interference and compatibility checks. Types of data typically obtained from hot bench testing are listed in subpar. 4-8.6. A mock-up of the electrical system of an air vehicle should include the following:

1. Power generation and storage devices and associated equipment to include generators, alternators, batteries, voltage regulators, transformers, and inverters. Any cooling and/or lubricating systems to be used with these components should be included in the mock-up to include ducts, piping, tanks, and valves.

2. Electrical distribution and control including wiring, cabling, contactors, switches, circuit breakers, fuses, and meters. Critical wire runs (power feeders, electrically unprotected wires, and congested area wiring) should also be included in the mock-up. Wiring should be representative of the final unit so installation techniques and hardware can be evaluated.

3. All items of electronic equipment to include communication and navigation systems, data bus, bus controllers, processors, panels and console structure, antennas, masts, and lead-ins. Fig. 6-3 provides an example of an electrical system functional mock-up.

The electrical system functional mock-up is usually limited for qualification purposes by its inability to simulate fully environmental considerations, shielding effects, etc. Algorithms
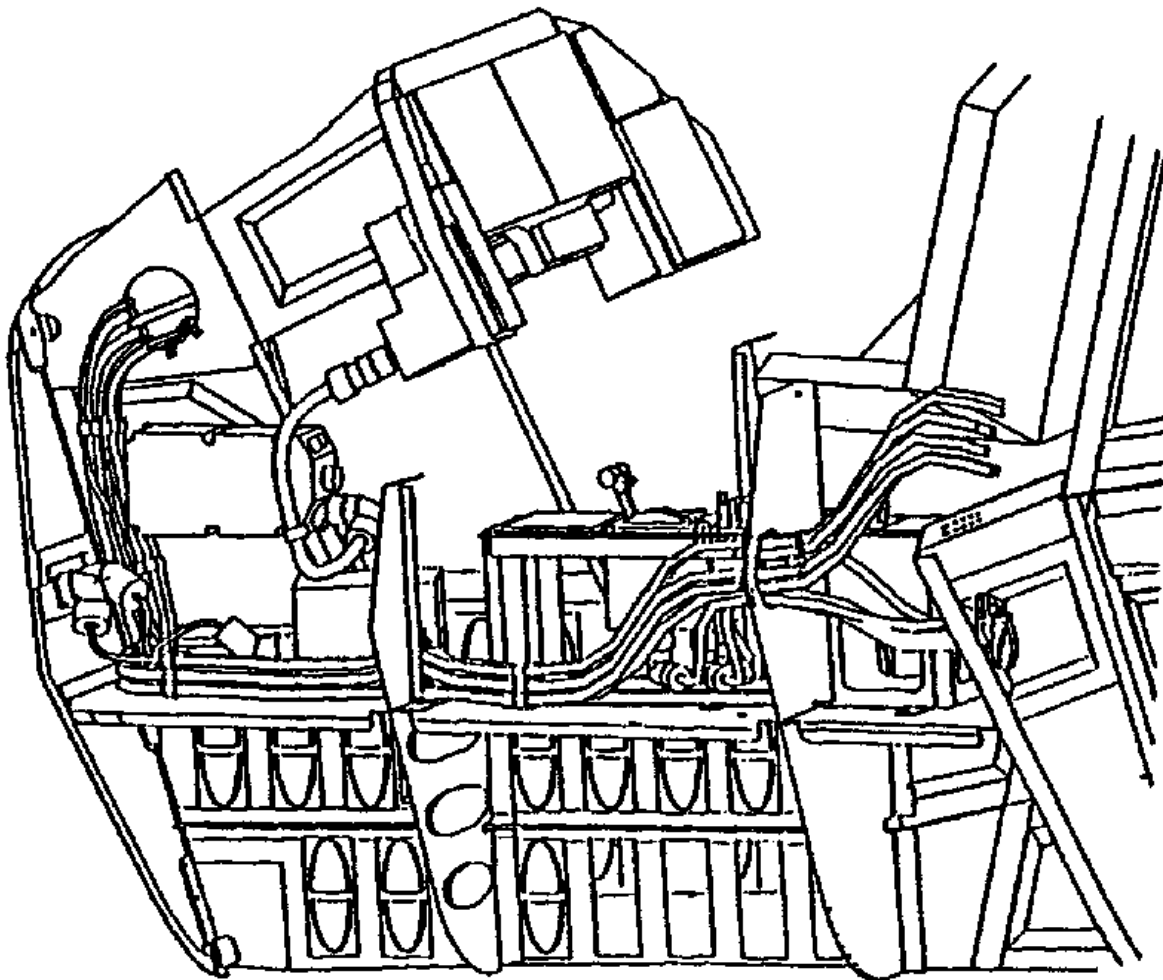
Figure 6-3. Electrical System Mock-Up

may not fully duplicate operational characteristics, etc. In addition, cost is often a major limitation.

6-4.2 PRESSURE SYSTEMS

Pressure systems include hydraulic systems, high-pressure pneumatic systems, and low-pressure pneumatic and vacuum systems. Pressure system mock-ups are intended to provide data and measurements leading to the determination that the pressure systems meet specification requirements. Qualification data that can be obtained from pressure system mock-ups include preflight data, pressure strength capabilities of vessels, fittings and tubings, and control logic.

6-4.2.1 Hydraulic System

A functional hydraulic system mock-up that is sufficient for dynamic test and preflight qualification of the system and its components should be fabricated. Major items of the hydraulic systems should be subjected to preflight qualification to demonstrate compliance with design and

operational criteria. Functional mock-ups should be fabricated for all hydraulic subsystems, such as rotor and propeller controls, turrets, door actuators, landing gear, and weapons subsystems.

The mock-ups should incorporate actual hydraulic system components with associated plumbing including main and emergency pumps, reservoirs, accumulators, filters, controls, and sufficient piping to show clearances. The hydraulic plumbing should approximate actual air vehicle requirements in terms of lengths, diameters, bends, and fittings, i.e., "production-type" lines and hoses. Also hydraulic mock-ups should include the actuator controller and software (if any).

Limitations of the hydraulic subsystem mock-up for substantiation of qualification requirements include the inability to simulate all environmental factors, actual air vehicle hardware may not always be available, prototype hardware may not exactly duplicate performance characteristics, and cost of fabrication might limit exact duplication of physical characteristics. For example, seals might function very well on a test stand yet deteriorate rapidly in a dusty environment, and/or a simulated pressure source may not duplicate pressure fluctuations found in flight.

6-4.2.2 High-Pressure Pneumatic Systems

High-pressure pneumatic subsystems requiring qualification tests are of the airborne compressor-charged and ground-charged storage bottle types. Hot gas subsystems normally are not reusable (at least not without refurbishment) and are considered a "one-shot" operation. Thus verification is accomplished through qualification and acceptance testing on a component basis. Another high-pressure pneumatic source is a sealed gas storage bottle, which can be used as an emergency
backup system, but this is also a "one-shot" operation.

Ground-charged air bottle subsystems are tested in the same manner as the airborne compressor-charged subsystem. To make the ground tests as realistic as possible, the test stand or apparatus should approximate actual air vehicle requirements in terms of lengths, diameters, bends, and fittings. The pneumatic subsystems should be properly lubricated, and all system components and attached linkages and mechanisms should be properly adjusted.

The mock-up should be adequate to determine whether
1. The various functions are accomplished satisfactorily.
2. The movement of all components is smooth and positive.
3. Relief valves, automatic devices used to terminate an operation, pressure controls, switches and signals, audible or other warning devices, and similar installations function as intended.
4. All indicating devices function and synchronize with the movement of the respective component, as specified.
5. The specified functioning pressures are controlled and not exceeded. Pressures may be obtained by normal system pressure gages, or electronic equipment, as applicable.
6. All tubing and fitting joints and component external seals are free from leaks.
7. All lines, fittings, and components are free from excessive movement and chafing.
8. There is full engagement of mechanical locks and catches.
9. The clearance for all moving parts throughout the entire range of movement is such that fouling of adjacent parts cannot occur.

10. All pneumatically operated doors and closures are flush with surrounding surfaces within limits specified.

11. Simulated normal flight operating conditions or any possible inadvertent operations will not cause system malfunctions.

12. Subsystems normally operated by the pneumatic system can be operated during an emergency.

A major limitation of the mock-up for qualification purposes is its inability to simulate environmental considerations such as vibrations and various climatic conditions. Also pressure spikes and fluctuations might vary considerably from actual airborne conditions.

6-4.2.3 Low-Pressure Pneumatic and Vacuum Systems

Low-pressure pneumatic and vacuum subsystems commonly are supplied by regulated bleed air from the engine compressor; however, this source could be simulated by some other means. The bleed air is normally at a very high temperature and pressure, and by necessity the ducting is insulated. If a high-pressure source is regulated to a lower pressure, the system should be capable of withstanding the higher pressure.

Extreme caution should be exercised by personnel handling these subsystems. Safety precautions should be outlined by the contractor.

A typical low-pressure pneumatic subsystem supplies pressure for an air-conditioning system, pressurizing a hydraulic reservoir, or any desired low-pressure pneumatic system. The bleed air pressure of the engine of the air vehicle should be regulated to the desired operating pressure with a pressure regulator. External electrical power and hydraulic power (for hydraulic-related subsystems) are required.

The functional mock-up is useful for checking for leakage, pressure drops, relief valve cracking, reset pressures, etc. A major limitation of the mock-up for qualification purposes is its inability to simulate environmental considerations such as vibrations and various climatic conditions. Also pressure spike and fluctuations can vary considerably from actual airborne operations.

A typical vacuum subsystem test procedure and apparatus similar to that described for the low-pressure pneumatic subsystem may be used. Vacuum subsystem mock-ups are typically used to calibrate and qualify instruments and instrumentation subsystems. It is useful for checking for leaks. Also it is useful for checking proper operation of the directional gyros and attitude indicators. Mock-ups of this type are prone to leak and usually limited in their ability to simulate actual environmental conditions. Vacuum characteristics might vary considerably from the actual air vehicle operational characteristics. Operational characteristics might not be well-defined.

6-4.3 ENGINES AND DRIVETRAIN, FLUIDS, AND ACCESSORIES

6-4.3.1 Engine

A functional subsystem mock-up for an engine is a facility and test bed (rig) that includes all that is needed for development and preflight qualification of the engine and its components. An engine mock-up of this type usually consists of a concrete enclosure—called a cell or a blockhouse—for operating personnel and controls, engine mounting rig, engine controls, instrumentation, data recorders, fuel system and source, exhaust duct, noise suppressors or equivalent, power absorber, and safety devices. The test setup should be assembled so that all of

the components are arranged in the proper spatial relationship. Accessories, such as particle separators (if any), should be installed to determine component arrangement and effects on the engine, external configuration, and performance. Instrumentation should be installed to measure pertinent parameters, such as compressor revolutions per minute (rpm), turbine rpm, pressures, lubricant temperature, flow rates, and torque. Components, such as reduction gearboxes, starters, starter generators, chip detectors, sensors, and oil coolers, also require unique test rigs and fixtures. These test rigs and fixtures are usually the property of the engine manufacturer or vendor furnishing the component. Typically, they may include a motor, pump, variable drive gearbox, fuel source, heat exchanger, load simulator, test instrumentation, gages, data recorders, and means for mounting the test article.

6-4.3.2 Drivetrain Assemblies and Components

A typical test bed (rig) for development and preflight qualification of drivetrain (transmission, gearboxes, bearings, couplings, shafts, etc.), fluids, and accessories may be either a regenerative-loop arrangement or an open-loop system. These test rigs are usually unique for every gearbox and transmission assembly. An open-loop rig requires full input power and a full power load absorber. The power absorber might be a water brake, dynamometer, or electric motor with suitable load banks, etc. The test rig is driven at normal operating speed by an electric motor, hydraulic motor(s), or other suitable prime mover. The regenerative loop captures part of the output power and feeds it back to the prime mover. Components, such as clutches, oil pumps, oil filters, and chip detectors, require unique test rigs and fixtures. These rigs and fixtures are usually the property of the vendor furnishing the component.

6-4.3.3 Engines and Drivetrain

Iron bird testing typically follows bench test. An iron bird, or propulsion system test bed, is used to concomitant testing of engines and drivetrain components. It is also used to evaluate the engine airframe interface, validate the control(s) design and installation(s), optimize the control functions, and evaluate maintainability. This test bed should include the entire propulsion and drive subsystem, such as rotor(s) or propeller(s), engine(s), auxiliary power units, transmission, and gearboxes. Also see par. 6-5 concerning the ground test vehicle.

The engine and drivetrain functional mock-up is useful for preflight qualification of engines, the drivetrain, bearings, gearboxes, couplings, etc. It is also useful for preflight qualification of engine components, fuel and oil systems, and other components. A secondary purpose could be maintainability and human factors evaluation if there were sufficient attention to detail. There are limitations. Typically, these types of mock-ups are not capable of simulating air inlet and exhaust pressures at all flight attitudes and velocities. Oscillatory and transient loads and vibrations cannot be exactly duplicated. Weapon exhaust flow is not easily duplicated on the ground and could affect both the engine and drivetrain.

6-4.4 ROTOR SYSTEM

The functional subsystem mock-up requirements for rotor system mechanical rotor and controls, rotor and electronic controls, and whirl test articles are discussed in this subparagraph. Many modern-day air vehicles use some form of hydromechanical or electrohydraulic controls. Hydromechanical systems are discussed in subpar. 6-4.4.1, and electrohydraulic systems are included in subpar. 6-4.4.2.

6-4.4.1 Mechanical Rotor and Controls

Except for maintainability, human factors, and accessibility-related functions, which should be accomplished on a full-scale mock-up or preferably a computer-aided engineering substitute for mock-ups, other functional tests of rotor and controls should be accomplished on component-, assembly-, and/or system-level functional mock-ups. Rotor forces could be approximated by means of cams, electromagnetic devices, hydraulic force generators, and solenoids. Complex loading can be approximated via computer-controlled devices. Fatigue testing typically includes some form of the previously mentioned devices, yet seldom (if ever) is it accomplished on a total system basis. Representative portions of the control system often are tested on a subsystem basis with simulated loads and rates. Integrated hub and mechanical control system testing should be done on a control system test bed, whirl stand, power system integration test stand, or ground test vehicle, which is discussed in par. 6-5.

The control system test bed should include a complete rotor hub and control system. It should also include all provisions for controlling the rotor, i.e., the swash plate, control rods, pitch horns, mixing levers, bell cranks, hydraulic actuators, and other hydraulic components, as applicable. Gearboxes with appropriate shafting should be provided for mounting; however, the rotor does not have to turn during control system testing. Rotor blade root sections typically are used in lieu of the complete blade assembly; but the blades could be attached.

This functional mock-up could be used to check for adequate clearance throughout the full range of travel while under load. Proof loading, stick loading, and leak checking could be accomplished. Rotational testing is typically accomplished on a whirl stand; see subpar. 6-4-4.3. For those rotorcrafts requiring blade folding, either this mock-up or the whirl stand should be capable of demonstrating compatibility of rotor and hub components during the complex geometric manipulations generally associated with folding. Blade folding might be manual or might be powered by one of the available secondary power systems. The folding operation, security of locks, and functioning of the "SAFE-UNSAFE" indicator should be demonstrated with a mock-up that duplicates the exact motions of the blades. Actual components should be used in the power system.

A secondary purpose of the functional mock-up could be to check the adequacy of the design for visual inspection and maintenance accessibility. For example, oil-level sight gages and appropriate access doors should be located so that the doors are accessible and the gages can be seen when the doors are open.

Complexity and cost of the subsystem integration test stand, ground test vehicle, and power system integration test stands are major limitations. Simulated masses, forces, rates, displacements, etc., only approximate the actual operating environment. Power system integration test stands or tie-down testing is the best form of ground testing; however, these too only approximate the actual operating environments. Aerodynamic and aeroelastic characteristics cannot be fully duplicated and evaluated on the ground.

6-4.4.2 Rotor and Electronic Controls

The rotor and electronic control functional mock-up should incorporate many of the physical features of the mechanical and hydromechanical subsystem; however, it should also include electrical control devices, such as wires, sensors, motors, processors, and computers. Also see subpar. 6-4.5 for information on electronic system manager network mock-ups. A hydromechanical functional mock-up includes most of the required features that are addressed in

subpar. 6-4.4.1. Rotors are rarely positioned directly by electric motors. Because of the large forces involved, such motors would be too large and heavy. For this reason, hydraulic actuators remain the preferred method to position rotor blades. Typically, they position the blades by placing forces on a swash-plate assembly that in turn moves pitch change links, blades, and rotor path. Gyroscopic effects are considered in the geometry. To set the position of the swash plate precisely, the hydraulic actuators are incorporated into a servomechanism containing an electronic (sometimes digital) compensation network, which steers the actuators to the correct position. Actuator position is measured by means of electronic sensors, such as linear variable differential transformers (LVDTs). The rotor and electronic control functional mock-up should incorporate these features.

Rotor forces, etc., can be simulated via the same means used for mechanical and hydromechanical subsystem functional mock-ups. This mock-up is useful for preflight qualification. In addition to the functions accomplished by rotor and mechanical mock-ups, limited software qualification is possible, although its effectiveness is limited by environmental effects. Also gains, rates, and loading can be approximated only during ground test controlling the movement of a hydraulic actuator assembly; see subpar. 6-4.5.

Flight control integration testing should be accomplished first and followed by power system integration testing. Computer and related software and firmware are tested by electronic simulation and bench test. Air vehicle tie-down testing or powered system integration test stands are the most complete means of ground testing. A power system integration test stand is sometimes called an iron bird. It duplicates most of the dynamic systems of the air vehicle, but it will not fly. Software can be verified during power system integration testing and flight testing. Actual operating conditions are approximated by this stand; however, aerodynamic and aeroelastic characteristics cannot be fully evaluated on the ground. The aforementioned testing is useful for preflight qualification. However, its effectiveness is limited by environmental effects.

Gains, rates, feedback loops, resonance conditions, etc., can only be estimated and approximated during ground testing. Optimization of gains, rates, and constants usually requires flight testing. Also electromagnetic vulnerability testing requires use of very specialized facilities. Subpar. 6-4.5 provides additional information concerning electronic control system functional mock-up requirements.

6-4.4.3 Whirl Test Article

Whirl testing subjects rotating aerodynamic components to their inertial and rotational forces. Although the operating conditions of rotors and propellers are similar in some respects, significant differences exist. Typically, whirl testing includes a tower approximately one rotor diameter in height, rotor hub and controls, electric motor, reduction gearbox, strain gages, load cells, track and balance devices, tachometer, means to measure deflection and angle of attack, hydraulic pump, actuators, safety barrier, and operations room. Whirl test rigs should be used for endurance testing, hover performance, aeroelastic stability testing, validation of nondimensional coefficients, and overspeed testing and to obtain data to update analytical models. Transition to hover and flight test is often based on good correlation between analytic predictions and wind tunnel and whirl test results. The test rig is limited to open-loop testing at low-wind conditions. Generally, only hover and in-ground-effect performance and stability testing can be accomplished.

In both rotors and propellers, a large amount of kinetic energy is in the assembly when it is rotating at operating speed. This makes a complete failure catastrophic. While this emphasizes

the importance of qualification tests, it also makes these tests difficult and possibly hazardous to perform.

Rotor system whirl tests are conducted prior to the first flight of the rotorcraft. As a minimum, the aerodynamic calibration of main rotor static thrust performance and the stress and motion surveys over the design range of combinations of collective and cyclic pitch and rotor speed should be obtained. Fig. 6-4 shows a typical whirl test rig.
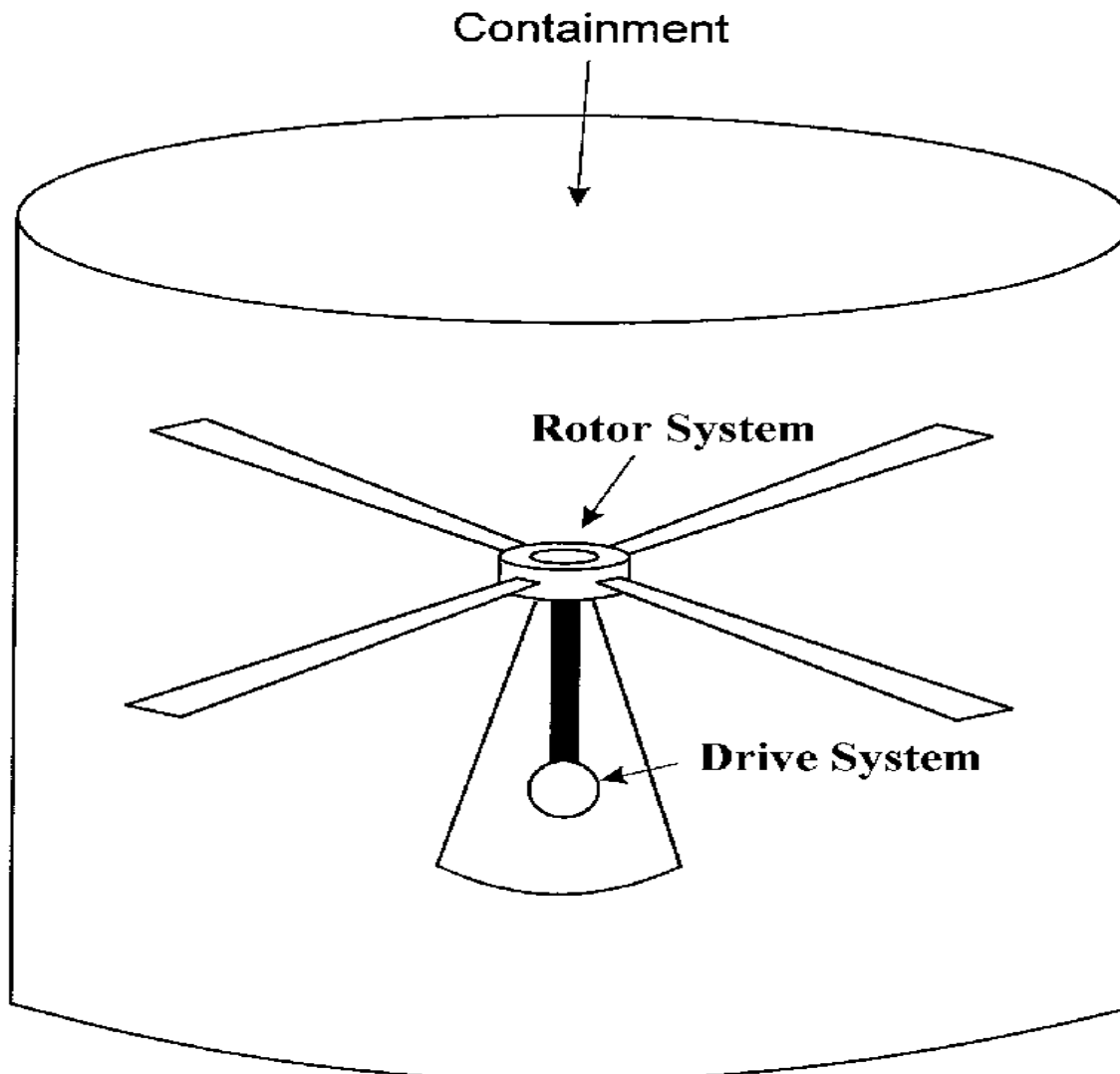

Figure 6-4. Whirl Test Rig

6-4.5 ELECTRONIC SYSTEM MANAGER NETWORKS

Electronic system manager network mock-ups consist of the processor hardware and software, memory, and input/output (I/O) devices. Since a functional mock-up of the electronic system manager must function with the same algorithms (coded into the software) and the same processor, the mock-up typically uses engineering development model hardware and preproduction software. As a result, functional mock-up tests approximate the same level of testing as test of the actual hardware. The data bus for functional mock-ups should satisfy the air

vehicle system specification for data communication to the maximum extent possible. Information concerning typical requirements and concepts of operation may be found in Society of Automotive Engineers Standard AS 15531, *Digital Time Division Command/Response Multiplex Data Bus*, (Ref. 4).

The use of "clean" laboratory power and grounds, different physical arrangement of the component, shielding differences, and differences in cable lengths between the mock-up and the actual hardware may affect the validity of the mock-up results.   Therefore, the mock-up should be as production representative as possible to reduce the impact of these variables.

6-4.5.1 General Control and Data Bus Networks

General control and data bus networks of mock-ups consist of the bus (i.e., the cable), the bus controller, remote terminals with their associated subsystem, and/or subsystems with embedded remote terminals, each with its associated software. Cable stubs are coupled to the bus through a coupling transformer or by direct connection to the bus and are coupled to the transmitter/receiver through an isolation transformer. The extent to which the mock-up hardware and software represent the actual system determines the applicability and limitations of the mock-up to provide valid qualification data. Control and data bus network hardware components, as well as component software, require qualification. A production representative control and data bus network may be used to provide qualification data. However, cost is a limiting factor to providing an adequate mock-up. Fig. 6-5 depicts a typical control and data bus network.
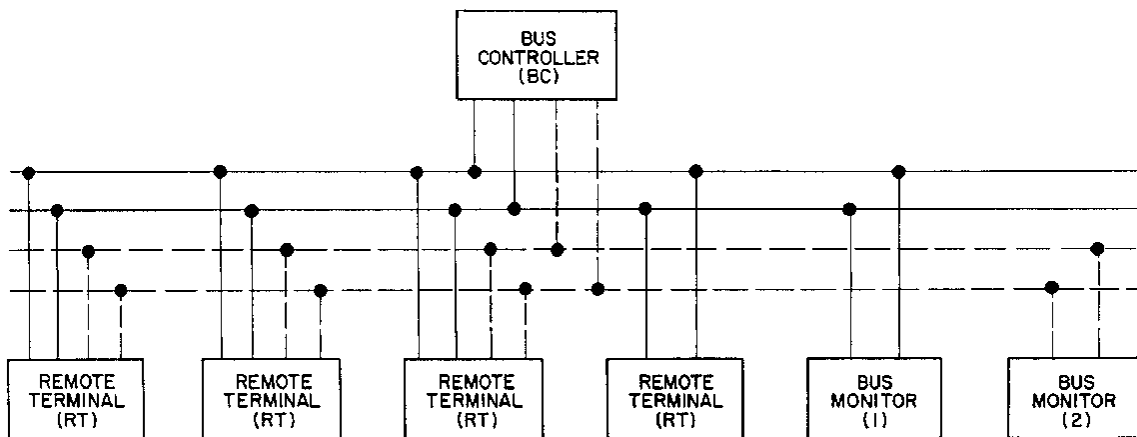

Figure 6-5. Control and Data Bus Networks

6-4.5.2 Electronic Flight Controls

Electronic flight control functional mock-ups could be of the analog, digital, or fly-by-light types. Older air vehicles typically used analog. Anytime a system is linear, i.e., it can be expressed in its entirety in the LaPlace "S" domain, analog construction is practical. However, the system might be more susceptible to noise. Fly-by-light systems are less susceptible to electromagnetic fields but more susceptible to temperature variations. Electronic flight control system mock-ups consist of position-sensing devices, actuators, the data/signal transfer medium (wire or fiber-optic cable), and processors. Except for system-specific hardware and possibly software, the functional mock-up is similar. The mock-up is used to determine that the system provides the appropriate control actuations for the given set of input conditions. Also see subpar. 6-4.4.2. The fact that the load forces on the system are simulated and not the actual loads

produced on the air vehicle limits the utility of such a mock-up. All systems require some form of shielding. Digital and fly-by-light systems require qualification of software and hardware. Cost is a major limitation, especially with fly-by-light systems and mock-ups.

6-4.5.3 Integrated Cockpit Avionics Networks

An integrated cockpit avionics network mock-up consists of the system control, displays, processors, interconnecting cabling, and associated software. It is used to evaluate the integration of subsystem and system hardware and software. The mock-up should include as much production representative equipment and wiring as possible. In addition, human interface considerations and data entry procedures may be assessed. Cockpit avionics integration requires qualification of software as well as hardware and requires in-flight evaluations in addition to the mock-up assessments. Flight evaluations are required because the laboratory environment only approximates the real world. Also initial cost is a major limitation of avionics network mock-ups.

6-4.5.4 Electronic Engine Controls

The electronic engine controls mock-up allows assessment of performance characteristics of analog and digital engine controls ranging from supervisory to full authority electronic control systems. Engine control mock-ups may assign mechanical and sensor functions to the hardware mock-up or simulate them on a computer, which substitutes a mathematical model for actual hardware. The computer interfaces with the mock-up by means of mechanical, electronic, and fiber-optic signals whose characteristics are similar to those received and generated by the hardware being substituted. As a minimum, the mathematical model should encompass both the engine and the rotor drivetrain. It can vary in complexity and accuracy (even considering air vehicle free body influences during maneuvers), the degree of which depends on the amount of fidelity required to substantiate the control methodology for performance and behavior before proceeding to flight test.

6-4.6 TARGETING, FIRE CONTROL, ARMAMENT, AND STORES STATIONS

Target acquisition and fire control systems are typically modeled by computer simulation and then tested on a hot bench that includes all of the essential electronic components. Models should also be developed for safe separation, jettison, and gravity drop of weapons and stores. Also the targeting, fire control, armament, and stores station installation should be completely mocked up, including fixed and movable weapons and accessories; turrets; rockets, guided missiles, and accessories; fire control subsystems; internal or external stores as applicable (including racks, supports, shackles, sway bracing, ejectors, etc.); dummy armor plate and bullet-resistant glass; and hoisting provisions, as applicable. The target acquisition and weapons sighting systems should be fully functional. The fixed and movable weapons, turrets, and fire control equipment should permit the full range of movement. Particular attention should be given to showing all armament installations in such detail that clearances (both ground and structural) and physical arrangement can be readily checked. The arrangement should be such that loading and unloading of missiles, rockets, and gun ammunition and removal and installation of guns may be demonstrated. Missile- or rocket-launching mechanisms should be completely mocked up and capable of movement through the normal operating travel. The mock-up should provide field of fire mechanical stops and safety interlocks.

If armor protection is specified, the mock-up should include the armor protection of the engine(s), auxiliary power unit(s) (APU), controls, wiring, and liquid-carrying lines, as well as flight crew stations. These mock-ups may also be used for operational testing training and maintenance demonstrations.

The targeting, fire control, armament and stores functional mock-up should be used for checking out electrical components interface, software, firmware, human factors, and for preliminary electromagnetic and compatibility checks. Typically, the mock-up might be limited by its limited ability to duplicate operational environments. Algorithms and weapons simulators might not duplicate actual performance. Target simulation is only an approximation. Clean laboratory power and less than exact physical arrangement of wires, cables, etc., might influence the results.

6-4.7 LANDING GEAR

Many air vehicles use skid-type landing gear in lieu of wheel-type systems. The choice of skid- or wheel-type landing gear is based on operational needs, which include but are not limited to low observable requirements. Typically, skid-type landing gear is developed and tested by the airframe manufacturer. It is essential that skid drop-test fixtures duplicate (as nearly as possible) the mass properties and stiffness of the airframe. Wheel-type landing gear, especially the retractable type, is normally developed by specialty companies. These companies usually have extensive facilities and functional mock-ups, such as drop, braking, hydraulic, and dynamic test rigs. Functional mock-ups of this type should be capable of simulating loads, spring rates, mass properties, and stiffness at various lateral and longitudinal contact angles. The mock-up of a fixed landing gear—including brakes, swiveling features, and accessories, such as floats and bear paws—should permit evaluation of accessibility to the air vehicle for personnel and cargo loading and unloading and of the effect of the gear on the maintainability of the air vehicle. Skid-type systems should include oleo struts, tow wheeling, etc. Several mock-ups may be needed to demonstrate high- and low-type gear, flotation gear, and ski-type systems.

Retractable landing gear mock-ups should demonstrate operation of the retraction mechanism (normal and emergency extension), fairing doors, and the positive lock provisions. Hydraulic and electrical retraction mechanisms should be fully functional. The kinematics of the retraction linkages should be operative in order to allow evaluation of possible interference with doors, hatches, or special exterior equipment while in any of the intermediate landing gear positions during the retraction or extension cycle. The mock-up should include representation of all equipment in the wheel well in order to determine possible interferences and environmental problems. The flexure of the lines and hoses for landing gear retraction, brakes, and drive power should be demonstrated in the mock-up. The addition of transparent panels to the mock-up structure aids in determination of the suitability of the wheels-stowed configuration and assist in determination of possible design faults.

An alternate means of supporting the mock-up at the static gross weight of ground position should be employed for air vehicles incorporating retractable landing gear. The size and shape of shock absorption devices are important in the evaluation of landing gear clearance and operation. However, simulation of the landing gear spring rate or load deflection characteristics may not be warranted or desired. Nevertheless, the mock-up has limited value for qualification (except for accessibility and maintainability) unless landing gear spring rates and load deflection

characteristics can be approximated. Clearance under load cannot be evaluated, and aerodynamic and other environmental factors cannot be inexpensively duplicated.

6-4.8 LIGHTING MOCK-UP

A full-scale functional mock-up of the interior and exterior lighting should be constructed. All modern air vehicles having moving maps and flight instrumentation on processor-driven cockpit displays or multifunction displays should have these displays included in the lighting mock-up. Lighting and reflections should be compatible with light-amplifying devices.

A full-scale mock-up should be used for lighting inspection and may be employed for crew stations, passenger stations, cargo compartments, and equipment compartments. An actual air vehicle cockpit or cockpit section should be provided, when practical, for inspection of cockpit lighting. If an actual cockpit or cockpit section cannot be employed for the cockpit lighting mock-up, the cockpit may be simulated. The framing, windows, windshields, bulkheads, and other cockpit sections that are visible to the pilot and/or copilot should duplicate those of the production air vehicle. Soft metals, plastics, and wood suitably coated to represent the production article may be used. The contractor should develop an interior and exterior lighting system mock-up checklist. Particular attention should be paid to the electrical power provided to ensure that the power available to the mock-up does not exceed that of an actual air vehicle.

Light-amplifying devices, such as night vision goggles, laser protection glasses and visors, and optical sighting devices, should be available for evaluation of lighting. This functional mock-up should be used for preliminary human factors and night vision evaluations; therefore, it contributes to preflight qualification. See subpars. 6-4.8.1 and 6-4.8.2 for the qualification limitations of lighting mock-ups. Early detection of problems is essential.

6-4.8.1 Interior Lighting

Complete interior lighting, with glare shields, should be mocked up. Moving, processor driven, and other multifunction displays should be included so that evaluation of compatibility in terms of glare, reflections, night vision, etc., can be performed. These should be functional displays. Provisions should be made for viewing the mock-up in a completely darkened room or by simulating complete darkness in the mock-up. Either a darkened room or red goggles should be provided for at least a 30-min dark adaptation. Passage from the cockpit lighting mock-up to any other lighting mock-up station or compartment in the should not require readapting observers to darkness. The mock-up should be illuminated with all instrument lights operative and should be provided with equipment identical to that to be installed in the operational air vehicle. In the case of instruments and console controls, the equipment to be installed or similar equipment (not pasteups) should be used. If controls that energize indicator lights cannot be actuated in the mock-up, the indicator lights should be energized by switches external to the mock-up or by internal switches not normally used for mock-up inspection. Adjustable dimming should be provided for all lights to allow the light intensity to be varied for the evaluation of night operations and the effects of glare. An actual blade assembly or blade section movable through its normal arc of rotation may be used to permit representative rotor reflections to be evaluated.

Provision should be made for inspection of the actual air vehicle cockpit or cockpit mockup section in daylight (bright sunlight) to determine the adequacy of warning lights, caution lights, etc.

The mock-up should be used for preliminary qualification of lighting, instruments, and displays. Preliminary qualification should include an evaluation of night vision compatibility characteristics. Early detection of problems is important. The use of prototype hardware, simulated displays, nonfunctional displays, and simulated cockpit arrangements and the nonavailability of the various light-amplifying devices for evaluation purposes limit the use of the mock-up for preflight qualification. Environmental effects and reflection of the airframe are not easy to duplicate. Reflections from a simulated disk in lieu of a rotating hub and blade assembly will not produce the modulated reflections of a rotating system. Also a simulated disk or a simulated hub and rotor system is not apt to have the same reflective properties. Typically, reflections and the modulating effects of a turning hub and blade assembly have not resulted in significant lighting problems.

6-4.8.2 Exterior Lighting

The location of exterior lighting should be duplicated in the mock-up. Provision should be made by the contractor to view the exterior lighting mock-up in a reasonably darkened area. Provisions should also be made to view the effects of external lighting on cockpit interiors (glare, etc.). Navigation lights, formation lights, landing and taxi lights, anticollision beacons, and high-intensity strobe lights should be demonstrated for visibility, light intensity, and flash frequency at the required azimuths and elevation angles. Structural, antennae, and external stores interferences with lighting patterns may be determined and corrective measures taken either by relocating the light or moving the obstructing appendage on the airframe. (See subpar. 6-4.8.)

6-5 GROUND TEST VEHICLE

A typical ground test vehicle is a nonairworthy air vehicle, airframe, or major portion of an airframe, which is used as a functional mock-up and test rig. Figure 6-6 shows examples of a ground test vehicle. Also a fully operational air vehicle could be tied down and used as a ground test vehicle. *CAUTION: The ground test vehicle should be analyzed and tested to ensure nonexistence of aeromechanical instabilities (ground resonance) and whirl mode instabilities. In addition, tie down of the air vehicle for this type of testing typically requires use of more than the normal parking tie down loads and hard points, and may require analysis of permissible tension loads on normally compression loaded fittings such as jacking points to react the projected force generated by the test conditions. Cargo hooks have been used as both a supplemental tie down fitting and for tethered hover testing in lieu of rigid tie down.* The ground test vehicle integrates propulsion, engine airframe interface units, software, and the rotor mechanical, electrical, electronic, hydraulic, and pneumatic systems needed for flight. This functional mock-up might incorporate all of these parts. It is used for airframe structural testing and dynamic component and rotor system evaluations. It provides confidence in the mechanical and structural integrity of the design necessary prior to the first flight. It may also be used to test the endurance of the propulsion and drive system in a manner less costly than flight testing. The ground test vehicle is a part of the progression from handmade component and subsystem mock-ups to early prototype hardware built from computer-aided engineering and computer-aided manufacturing proof articles integrated into a production representative system.
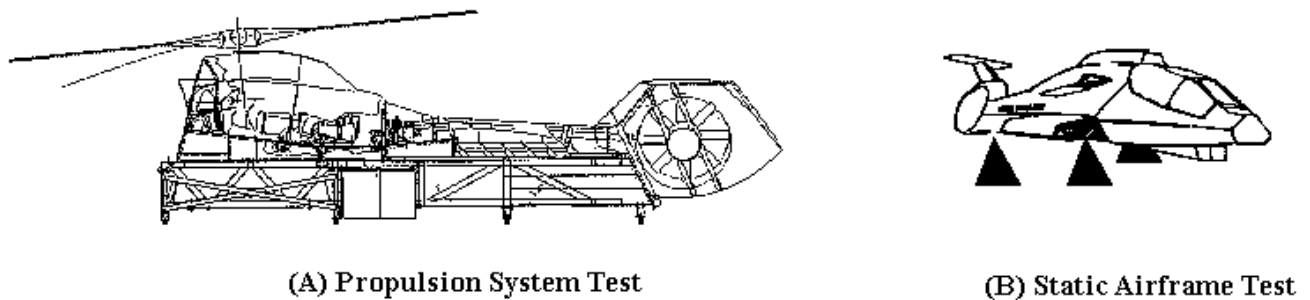
(A) Propulsion System Test   (B) Static Airframe Test

Figure 6-6. Ground Test Vehicle

6-6 MOCK-UP REVIEW AND APPROVAL

Mock-ups can be used to obtain an early determination of an actual air vehicle for service use. These mock-ups should provide a full representation of the physical arrangement with sufficient detail to permit checking compatibility with handling, maintaining, loading, and operating requirements for the air vehicle and its equipment. Also these mock-ups should be sufficient for checking crew and passenger stations, cargo and weapons provision, equipment arrangements, propulsion system installations, vision, clearance, lighting, personnel safety, etc. MIL-M-8650 (Ref. 2) provides additional information on planning mock-ups, mock-up reviews, scheduling and content of evaluations, and evaluators. Mock-up inspections are often accompanied by other visual data such as compartment layout drawings and air vehicle subsystem and hardware drawings, photographs, illustrations, an external vision plot illustrating the field of vision around the air vehicle from the crew's normal eye position per the Aitoff Equal Area projection vision plots defined in MIL-STD-850 (Ref. 3), and tabular photometric data from the lighting mock-up. Specific evaluation procedures should be established prior to an official mock-up demonstration to include definition of any objective scoring techniques and necessary tools or devices such as stopwatches, motion picture photographs, special lighting, and evaluation check sheets. For additional information relevant to evaluation, see MIL-H-46855, *Human Engineering Requirements for Military Systems, Equipment, and Facilities*, (Ref. 5).

Standardized design and mission suitability checklists are typically used to augment and/or provide guidelines for the evaluation of the mock-up. The inspection team should have sufficient time to review the mock-up, take measurements, review necessary criteria documents, and prepare comments prior to the critique. Mock-up review may include observing personnel representing the 5th percentile female through the 95th percentile male who are wearing Army flight clothing, arctic clothing, and survival equipment and performing mission functions, including ingress and egress, under night lighting conditions. Measurement of seat, panel, control, and other spatial relationships within the crew and passenger compartments may be evaluated.

An evaluation of the alternate uses of certain areas of the fuselage for various operational functions may be desirable, e.g., the operation of weapons from the doors or elsewhere through blisters or cutouts in the passenger compartment. The size of the hatches, particularly for the crew, may be strongly influenced by the access routes to the hatches within the crew compartment. Internal equipment obstruction should be evaluated together with the possibility of using the console, instrument panel, and seat bottoms or seat backs as steps to facilitate rapid egress from the compartment. Evaluation of the mock-up will identify any changes needed to

assure that the emergency escape paths are not compromised by external fuselage projections, such as pitot heads or antennas, which might injure the personnel or impede their exit from the air vehicle.

A crashworthiness inspection should be conducted using the checklist in USAAVSCOM TR 89-D-22, *Aircraft Crash Survival Design Guide, Vol. I, Design Criteria and Check Bits*, (Ref. 6). The specifications, standards, and other documents referenced in the aircraft detail specification should be the criteria upon which judgments of contractual compliance are made. Design areas that do not comply with the detail specification or system description and other problem areas should be documented as either deficiencies or shortcomings on the form prescribed by the procuring activity. If it is practical, recommended design solutions to mock-up problem areas should be incorporated into the mock-up during the inspection.

If required, mock-up approval should be granted upon the contractor's compliance with the required changes and/or approved deviations, as specified by the procuring activity. The contractor should provide photographs of the approved mock-up. Table 6-3 provides a sample checklist for a seats and furnishings mock-up review.

TABLE 6-3. SAMPLE BASELINE CHECKLIST FOR SEATS AND FURNISHINGS

Crew Seats	1. Are the vertical and fore and aft adjustments accomplished separately (versus integrated operation)? 2. In what increments can the adjustment be made? 3. Where is the adjustment control located? 4. Is the location satisfactory? 5. Is the seat designed for the proper equipment? 6. Is the seat equipped with a correctly mounted inertial reel with a "stalock" feature? 7. Is there an indicator or reference point provided so that the crew can determine the correct eye level?

Passenger Accommodations	1. Are the passenger seats provided appropriate to the passengers to be carried?
	 2. Is adjustment provided for the seats?
	 3. Are satisfactory safety belts provided?
	 4. Are shoulder harnesses and inertial reels provided?
	 5. Are seats designed for the appropriate mission equipment?
	 6. If litters are provided, are the following satisfactory?
	     a. Vertical distance between litters
	     b. Height of topmost litter above an in-flight stable surface
	     c. Aisle space between litters?

SECTION II

SIMULATIONS

6-7 INTRODUCTION

Simulations are the physical or mathematical emulation of characteristics of the physical equipment, its environment, events related to the equipment, or intelligence. The objective of a simulation is to reproduce certain aspects of the real world as part of the airworthiness qualification process. Qualification by simulation is desirable when the achievement of real-world situations is either prohibitively expensive, requires obsolescent time frames, or is dependent on remote or unpredictable natural occurrences. The qualification that is feasible to be performed through simulation is dependent upon how representative the simulation is of the actual system and its environment.

6-7.1 ABSTRACT EMULATION

Abstract emulation is used for concept exploration, design optimization, and tradeoff studies. It is necessary when economic and technological considerations render real-life measurements impractical, especially when prototype and test equipment do not exist and the technology to build it is not yet available. For example, air vehicle performance characteristic models allow assessment of a system over a wide variety of conditions for which actual measurements at each condition would not be practical.

Abstract emulation is the description, in mathematical terms, of the characteristics of a system. These system characteristics are described by means of equations (algebraic, geometric, statistical, and differential), logical rules, constraints, tabular data, graphs, and charts. The finished product, a model encompassing these characteristics, is verified by using critical test cases strategically chosen to assess the ability of the model to predict the behavioral response of a system across all its different modes of operation, such as rolling, yawing, and pitching of an air vehicle. The model is considered satisfactory when its predictions are reasonable and agree with test data within tolerances proportional to the criticality of the prediction. Typical applications include preflight envelope exploration, test data analysis, and development of subsystem models that will be incorporated into larger models, such as battle engagement models.

6-7.2 PHYSICAL EMULATION

A physical emulation consists of a digital model adapted to output a specific response signal, equivalent control driver, or generate video to emulate an actual system, subsystem, or environmental characteristic. Physical emulations can be individual black boxes to emulate a specific subsystem interface or a computer that emulates the response and control signals of several components or subsystems simultaneously. These techniques are useful for assessing interface characteristics in the absence of the actual hardware. For example, in the course of developing a targeting and fire control system, the actual air vehicle electrical and control interfaces might be emulated using computer-generated signals until the actual air vehicle is available for interface and integration tests. Physical emulation "substitute parts" are also appropriate for functional subsystem mock-ups, flight simulators, and mission simulators. These physical emulations are used in those circumstances to save cost and make the simulation or mockup more effective or realistic.

6-8 SIMULATION BASES AND VALIDATION CRITERIA

This paragraph discusses various forms of simulations and representations of the physical characteristics that may be modeled mathematically. Simulations may be based on many different types of models, including tabular data, characteristic function, transfer function, statistical function or characteristic, and artificial intelligence. When all of these models are used, it is imperative that the underlying information and analysis techniques used to create the models are understood. Failure to do so will potentially result in the misapplication of the model and consequent invalid conclusions. Not only must these issues be thoroughly understood, but the models must have undergone thorough validation prior to their use. The criteria used to demonstrate validation should be established based on the type of model and the use of the model or simulation output.

6-8.1 TABULAR DATA MODELS

Tabular data models are simple models in which data are presented in a tabular manner. Standard atmosphere data are usually presented as a tabular data model. Given an altitude value, a simple table lookup provides information such as temperature, air pressure, density, speed of sound, and coefficient of kinematic viscosity. Tabular data models are generally used where mathematical representation of that data is extremely complicated and/or requires large amounts of calculating capacity and time. This type of model is applicable in situations in which frequent and ready access to the data is required without the need to perform lengthy or difficult calculations. Engine performance data used in many flight simulators are examples of the uses for a tabular data model. This method of modeling is limited by the fact that the data are readily available only at the specific table values and data for intermediate values not tabulated must be obtained through interpolation. These models must be validated through systematic comparison of measured values at known points with the modeled values throughout the entire range of the model.

6-8.2 CHARACTERISTIC FUNCTION MODELS

Characteristic function models are developed through a process of fitting experimental data to a postulated mathematical representation of the data. Given a set of observations, it is sometimes convenient to reduce the amount of data to a model that depends on the values of observed parameters. An example of such an application might be the modeling of the pitching moment coefficient as a function of angle of attack. This is accomplished by "best fitting" the model to the data. The least squares method is most often used and can be applied to numerous models including straight-line, polynomial, and nonlinear models. It is also possible to develop confidence limits on the estimated model parameters. The validation process is further complicated if the calculated data are functions of multiple variables and the experimental process does not allow direct control of all variables simultaneously.

6-8.3 TRANSFER FUNCTION MODELS

Transfer function models are a subset of differential equation models used to model nonlinear physical devices. Complex devices tend to be described by nonlinear differential equations. Items in this category include aerodynamic, structural, thermodynamic, and electronic devices. Many nonlinear dynamic equation models must be solved by numerical computer

simulation because exact closed form solution equations for them do not exist. When nonlinearities are insignificant, a system may be described by using linear differential equations. These can also be organized into dynamic equations; however, they can also be left in the order in which they appear in the system being modeled. Doing this, the particular elements (or equations) described by differential equations are organized into transfer functions. Transfer function models are used to analyze dynamic system characteristics. The transfer function of a continuous system is described in the S-plane by Laplace transforms. The transfer function of a system is the ratio of the Laplace transform of the time-varying input to the system and the Laplace transform of the time-varying output of the system. Thus, by applying the method used to find the inverse Laplace transform, system characteristics can be determined based on the transfer function and the Laplace transform of the input function. Transfer functions have the characteristic that for a system in series (The output of the first component becomes the input to the second component.), the transfer function of the system is the product of the transfer functions of the components. Since the process of taking the Laplace transform is a mathematical integration process and the inverse Laplace transform is a contour integral in the complex plane, these transformations can be readily performed digitally or by use of electronic analogs. Usually outputs from transfer function models include frequency response characteristics.

Sampled data systems (usually digital) use Z-plane analysis techniques, which are similar to (because they are derived from) Laplace transform techniques. These analysis methods apply to linear systems, and any significant deviation from the linear assumption by the real-world system negates the use of this approach.

6-8.4 STATISTICAL FUNCTION MODELS

Statistical function models are used to model data results that are stochastic (random) in nature. Random variables are variables whose value cannot be determined beforehand but whose behavior can be described in terms of statistical functions. The basic steps necessary to develop a statistical function model are to (1) gather data representing the random variable, (2) make a graphical representation of the data in terms of either their frequency distribution or their cumulative density function, (3) postulate a model that represents the data, (4) calculate the parameters of the postulated model, and (5) perform a goodness-of-fit test to determine how well the data fit the postulated model and calculated parameters. Statistical functions include the normal distribution, the exponential distribution, the uniform distribution, the gamma distribution, the beta distribution, the Weibull distribution, and the bivariate normal distribution. Special probability paper has been developed to assist in the graphical interpretation of statistical data. Data fitting a normal distribution, for example, would appear as a straight line on normal probability paper. Methods used to estimate function parameters include maximum likelihood estimators and method of moment estimators. Methods used to determine goodness of fit (which forms the basis for model validation) include the chi-square test and the Kolmogorov-Smirnov test.

6-8.4.1 Statistical Results

Statistical results are often assumed to follow a normal distribution (sometimes referred to as the bell-shaped curve). The two parameters defining this distribution are its mean and its

standard deviation, which is sometimes referred to as sigma. These two parameters may be estimated from a sample by calculating the sample mean and sample standard deviation. The mean is a measure of the central tendency of the data, i.e., what is the most likely value of a random variable drawn from that population. The standard deviation is a measure of the dispersion of the data about their most likely or mean value. For a random variable drawn from a normal distribution, there is a 0.50 probability that it will fall below the mean, a 0.1587 probability that it will fall below the mean minus one sigma, and a 0.0013 probability that it will fall below the mean minus three times sigma. These are usually referred to as the average, expected minimum, and three-sigma values. Sometimes a five-sigma value (referred to as "Murphy's Law") may be calculated. This corresponds to a 0.0000002867 probability of occurrence. These values must be used with caution, especially at the extreme three- and five-sigma points because their validity depends on how well the true physical characteristics correspond to a normal distribution.

6-8.4.2 Monte Carlo Results

A Monte Carlo analysis shows how a system performs as configurations, topologies, and other parameters vary. It is necessary when a sensitivity analysis is impractical or when too many parameters (usually more than five) exist to sweep them, such that all combinations are represented (multidimensional sweep), while tabulating or plotting performance. The Monte Carlo analysis is useful for both measurements and optimization efforts. Because of its flexibility, it is a powerful tool useful to many disciplines. When the ultimate value or outcome of a parameter is a function of multiple stochastic variables combined in some form—additive, multiplicative, etc.—it is useful to develop a Monte Carlo simulation of the outcome. This may be necessary because the probability distribution of the combined variables cannot be derived in mathematical functional form. Generically, the Monte Carlo simulation method is based on using an algorithm that produces a pseudorandom number. A pseudorandom number is a number generated by a deterministic program that produces an apparently random sequence of numbers. This pseudorandom number, usually from a uniform distribution between 0 and 1, may then be converted to the desired distribution with appropriate parameters by using either transformation or rejection methods. Similarly produced random variables may then be combined according to the physical situation being modeled to produce a simulated result. This process is repeated a large number of times, and a statistical distribution of the system parameter may be determined. The number of simulation runs required to obtain valid data is a function of the variability of final result and the desired precision or confidence required of the simulation. As the scale of the simulation increases, the number of required simulation runs grows correspondingly. An example of the use of a Monte Carlo simulation would be to model the total error of a system based on the knowledge of the contribution of individual error sources.

6-8.5 ARTIFICIAL INTELLIGENCE (AI) MODELS

There are different classifications of artificial intelligence (AI) systems. One of the main applications is machine learning. An expert system makes use of machine learning. However, AI does not always involve machine learning. Hybrid systems use traditional procedures in conjunction with AI. See subpar. 6-8.7. AI expert systems are computer-based systems that use knowledge, facts, and reasoning techniques to solve problems that would normally require the abilities of human experts. These systems are usually based on rules or experience information about the behavior of a real-world situation. A rule might be of the form, "If condition x exists,

condition *y* exists, and condition *z* exists, a likely result of these conditions is situation *b*.". A large body of such rules can be very quickly evaluated for a specific situation, and the expert system then arrives at likely conclusions concerning the situation. Expert systems are useful to state these rules formally and develop an experience base. As the number of rules to be processed becomes large, the processing time increases. This aspect may limit the applicability of the method when time-critical situations are involved. A properly developed expert system might be useful as a replacement for a human expert or to arrive at conclusions much more rapidly than a human. Rule-based expert system applications applicable to the airworthiness qualification include performance data analysis, event result prediction, and diagnostic aids.

Logical inference engines are subsets of an expert system. A logical inference engine attempts to find a pattern in cause and effect data. A patient teacher is a system that is initially tolerant of faulty output. Skillful opponent is an application from game theory. Artificial intelligence has not yet been applied to qualification at the system level. However, AI can and should be used for other work, such as battlefield and threat simulations, vulnerability analysis, survivability analysis, and logical modeling. See subpars. 6-10.5 and 6-11-3. An expert system is limited by the expertise built into the system; therefore, it should not be used for life or death decisions. More advanced computers should make more difficult and complex modeling possible.

6-8.6 NEURAL NETWORK MODELS

Neural network models are based on the principle that they gain knowledge through experience and develop a set of hidden rules, whereas expert systems operate on a set of formally stated rules. The neural network absorbs its experience as part of a training or learning process. These networks have been applied to speech recognition, pattern recognition (including target detection), and perception (color, brightness, and three-dimensional form). Validation is performed by comparison of model outputs with known real-world data. Performance may be quantified in terms of percent confidence or accuracy in the predicted results. The validation effort should include the search for inadequate or incorrect branches within this tree. A neural network is programmed by forcing the network to reproduce the response from some reference system. Both the neural network and the reference system are exercised at certain data points (or experiments) during which time the internal parameters of the network are tuned so that its outputs respond identically to the output of the reference system. The programming process scans and rescans the various data points until the neural network reproduces everything without further tuning. Hopefully, the tuning effort inherently captures (within the set of internal parameters) every degree of freedom of the reference system. If so, the neural network can accurately predict all responses of the reference system, even experiments not used during programming. However, if the network does not inherently contain a complete description of the reference system, the predicted responses will become less accurate as experiments deviate farther from the calibrating (programming) points. To be useful, a neural network must be able to respond accurately to signals that are "between" the programmed data points. Doing this, the network covers the complete range of interest, i.e., all of the relevant degrees of freedom. Examining between the data points (over the relevant degrees of freedom) should be a part of the validation effort. To achieve this goal, three issues should be considered. They are

1. All of the relevant character traits (degrees of freedom) of the reference system must be contained within the set of data points used for programming. A trait can be explicitly

demonstrated by a specific experiment (like an individual equation) or implied by the behavior across many data points (like a system of equations).

2. The neural network must have the topology (layout) and capacity to describe, store, and reproduce the degrees of freedom of the reference system.

3. The neural network must have the ability to extract implied information across many data points—similar to solving a system of equations. Also the neural network must contain all of the relevant degrees of freedom, even if they were not explicitly described in any one experiment. By doing this, the network absorbs the general rules of the reference system as it looks across the data points; therefore, it can respond accurately to data points that were not programmed explicitly.

6-8.7 COMPOSITE AND HYBRID BASES

The modeling tools of par. 6-8 may be combined to form composite or hybrid models of bases of data. For example, system characteristics may be measured in order to arrive at a statistical description of a system, which could then be used as the basis for a Monte Carlo simulation to model situations not measured in the original data collection process. As another example, the formally stated rules of an expert system could be combined with the learned rules of a neural network to arrive at a hybrid system that applies both techniques. This additional degree of abstraction compounds the validation process in that it presents a wider array of situations and conditions that must be assessed prior to concluding that the model yields valid results.

6-9 EMULATORS

6-9.1 INTRODUCTION

Emulators are designed to duplicate the behavior, properties, or performance of another system and are often used to generate inputs for other models and simulations. The aspect being emulated may be the system equipment, an environment, an event, or intelligence, as discussed in the subparagraphs that follow. A physical emulator tangibly interacts with the remainder of the system and effectively replaces the subsystem it emulates. Abstract emulators provide the information to assess what the interaction would be under specific conditions in order to allow system designers to predict what the interaction would be if the emulated situation were present. As discussed in subpars. 6-7.1 and 6-7.2, emulators may be either abstract or physical.

6-9.2 SYSTEM EQUIPMENT

As introduced in subpar. 6-7.2, system equipment emulation is used during development of a subsystem or component when it would not be practical or possible to duplicate all system interfaces. For example, during the course of temperature and vibration testing of a piece of electronic equipment, it may be necessary to emulate the signal inputs to and outputs of the system under test by using system equipment emulators for items such as controls and displays. The rationale for the use of equipment emulators at this stage of the qualification process is the impracticability of testing the entire system.

6-9.3 ENVIRONMENTS

Some environmental parameters may be critical to the qualification process, yet due to the nature of the environment, the qualification process may require the use of emulations.

Determination of qualification-critical environments should be done early in the development process. Table 6-4 provides a matrix of environments that may be emulated. Emulation of these environments is often necessary to evaluate performance in a controlled setting. The natural occurrence of these environments is often unpredictable and uncontrollable and therefore necessitates their emulation. In addition, environmental emulations are sometimes required due to cost limitations of conducting tests at remote sites.

6-9.4 EVENTS

As with emulation of environments, emulation of events is useful when the natural occurrence of an event is random and it is not practical to wait for its occurrence or when the occurrence of the event must be carefully timed in order to monitor the system response. For example, in order to assess the testability of a system, a failure event must occur that exercises the capabilities of the system. To wait for the natural occurrence of all possible failure events in order to determine testability, real-time performance would not be practical. The occurrence of failure events may be emulated through a process of fault insertion either physically or through appropriate stimulus of the system. Determination of the number and types of events to be emulated could be derived from a statistical modeling of the failure frequency of the emulated faulty component or through a Monte Carlo simulation. Use of statistical versus Monte Carlo models is discussed in subpars. 6-8.4.1 and 6-8.4.2. Event emulations must be validated for use in meeting qualification requirements. Validation issues include ensuring the correct statistical model is being used to represent the system being qualified. In addition, event emulations may not be totally satisfactory to meet all qualification requirements because certain events, which might actually occur naturally, would be avoided in an emulation environment. These would include events that could cause damaging secondary failures or would create a hazardous situation. Other simulated events include the occurrence of emergency conditions or actions by the enemy.

6-9.5 INTELLIGENCE

Intelligence emulation involves emulation of skills, judgment, knowledge, and applied doctrine. This type of emulation is one of the more complex types of emulations because of the difficulties involved in modeling human behavior.

This type of emulation may be used to represent the actions of a friendly or adversarial person in a larger simulated environment. This could be achieved using prerecorded scenarios, artificial intelligence, or neural networks. It would be useful in a qualification effort when assessments require consistent emulation of human activities. (See subpar. 6-8.5.) Validation of these emulations requires determination of the extent to which the emulation accurately represents the real world in relation to how it is intended to be used.

TABLE 6-4. EMULATED ENVIRONMENTS

ENVIRONMENT	PARAMETERS	MODEL BASIS	APPLICATIONS
Climate—Ambient	Altitude Temperature Pressure Humidity	System specifications, table of standard values for atmosphere and altitude, geodetic surveys, and climatic tables	Abstract or physical emulations, such as algorithms and software for use of aerodynamic performance
Climate—Local (within a system)	Temperature Pressure Humidity	System specification requirements and table of measured values	Abstract or physical emulations for thermodynamic analysis
Operational Signal Interface	Voltage Frequency Waveform Phase shift Impedance Protocol Physical qualities (Temperatures, Pressures, Rates, etc.)	Interface control specifications and measured values (input and output) by means of various sensors and actuators	Physical emulations of input and output commands to and from sensors and actuators, along with sensor and actuator dynamic response, accuracy, and authority
Operational Tolerance Inter-face	Measures of accuracy plus or minus, percent, amplitude, volts, amps, etc.	Signal definitions as determined from interface control specifications and measured values	Abstract or physical emulations, such as error assessments and firm-ware for subsystem testing
Operational Control Interface	Position Speed Temperature Pressure Accelerations On and off commands, etc.	From physical plant, available and measurable data as integrated into signal flow graphs, state diagrams, and block diagrams	Abstract or physical emulations of system to calculate stability and control margins, transient response, etc., for use in simulated performance testing
Spatial Location	Latitude Longitude Altitude Orientation	Geographic surveys, digital mapping, global positioning data, and coordinate system	Abstract or physical emulations for use in navigation and targeting models
Atmosphere—Ambient	Wind Turbulence Ice Fog	System specification requirements and table of measured values, meteorological statistics	Abstract or physical emulations for use in transient response calculations and simulated performance testing
Atmosphere—Aerodynamic	Temperature Pressure Density	System specifications, table of standard values for atmosphere and altitude, geodetic surveys, and climatic tables	Abstract or physical emulations such as algorithms and software for use of aerodynamic performance
Terrain Obstacles	Woods Mountains Swamps, etc.	System specifications, geodetic surveys, digital mapping, photographic maps	Abstract or physical emulations for use in simulated performance testing
Electromagnetic Field and Noise	Frequency Bandwidth Peak power Mean power, etc.	System specifications, intended operational environment, table of measured values	Abstract or physical emulations for use in design analysis and simulated performance testing
Smoke and Obscurants	Density Drift rate Type and length	System specifications, experimental results, tables of measured values	Abstract or physical emulations for use in simulated system performance

			testing

6-10 SIMULATORS

6-10.1 INTRODUCTION

A simulator is a physical model and simulation of a weapons system or piece of equipment that is not a prototype but which replicates some major aspects of the operation of the equipment. It may include elements of imbedded computer hardware and software associated with these operations or the environment immediately impacted by the equipment itself, but which is reactive only to the manipulation of the single piece of equipment. Simulators are intended to expose equipment developers, operators, and maintainers to specific aspects of system operation without the necessity of the actual system. Simulators may be used to evaluate and assess system characteristics as well as training.

6-10.2 MISSION EQUIPMENT

A mission equipment simulator is used to assess the operation and integration of the mission equipment of the air vehicle. For example, a mission simulator might include controls and displays, a target detection system, communication and avionic equipment, weapons, and navigation components. Such simulations are implemented by combining and integrating system equipment simulations with environmental simulations. As part of a qualification program, they provide the confidence that mission equipment integration issues have been properly addressed. Fig. 6-7 provides an example of a mission equipment simulator.
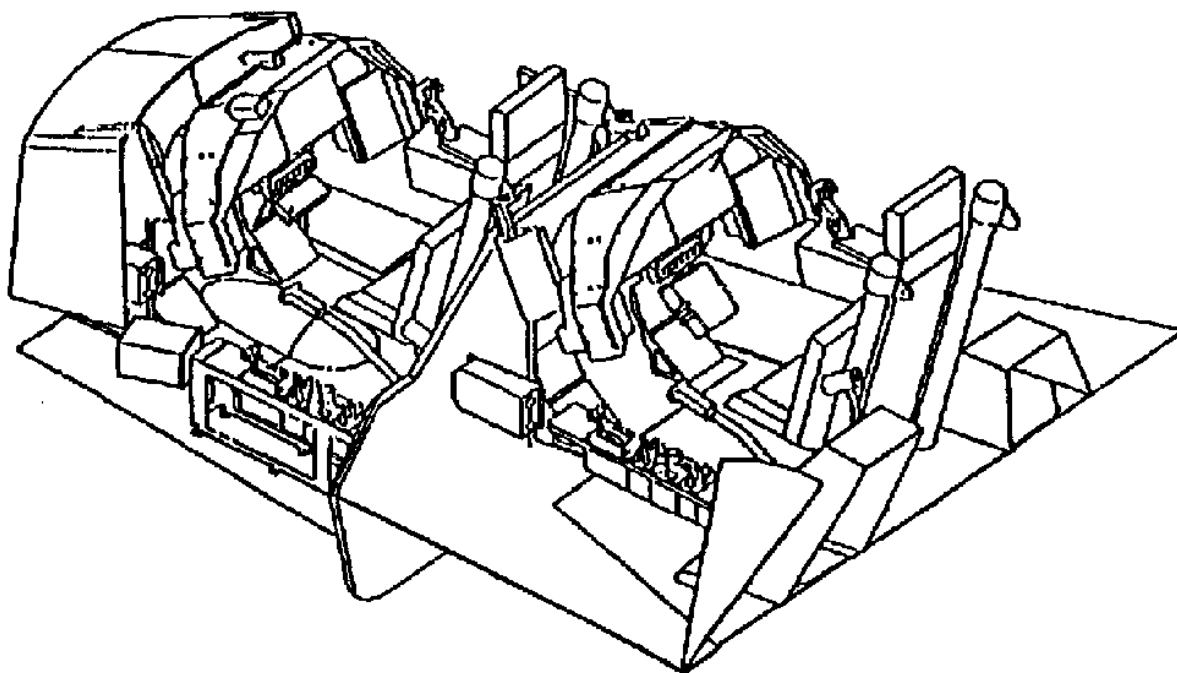

Figure 6-7. Mission Equipment Simulator

6-10.3 FLIGHT SIMULATORS

Flight simulations provide the flight crew with a moving platform and displays that react to their air vehicle control inputs in a manner similar to the actual air vehicle. The simulators incorporate system equipment simulation, environment simulation, and event simulation. Flight training simulators are used to provide procedural and flight training to pilots and therefore should replicate the total system to the maximum extent possible. Flight simulators may be used to evaluate the design of air vehicle handling qualities and system integration issues prior to building an actual airframe. It is important to understand the impact and limitations of motion and visual representations in these "fly-before-build" simulators. In addition, flight simulators may be used to evaluate flight envelope expansion impacts. In the qualification process they provide early indication of man-machine interface issues and thus provide another important element in the step-by-step buildup of confidence in the design. An example of a flight simulator is presented in Fig. 6-8.
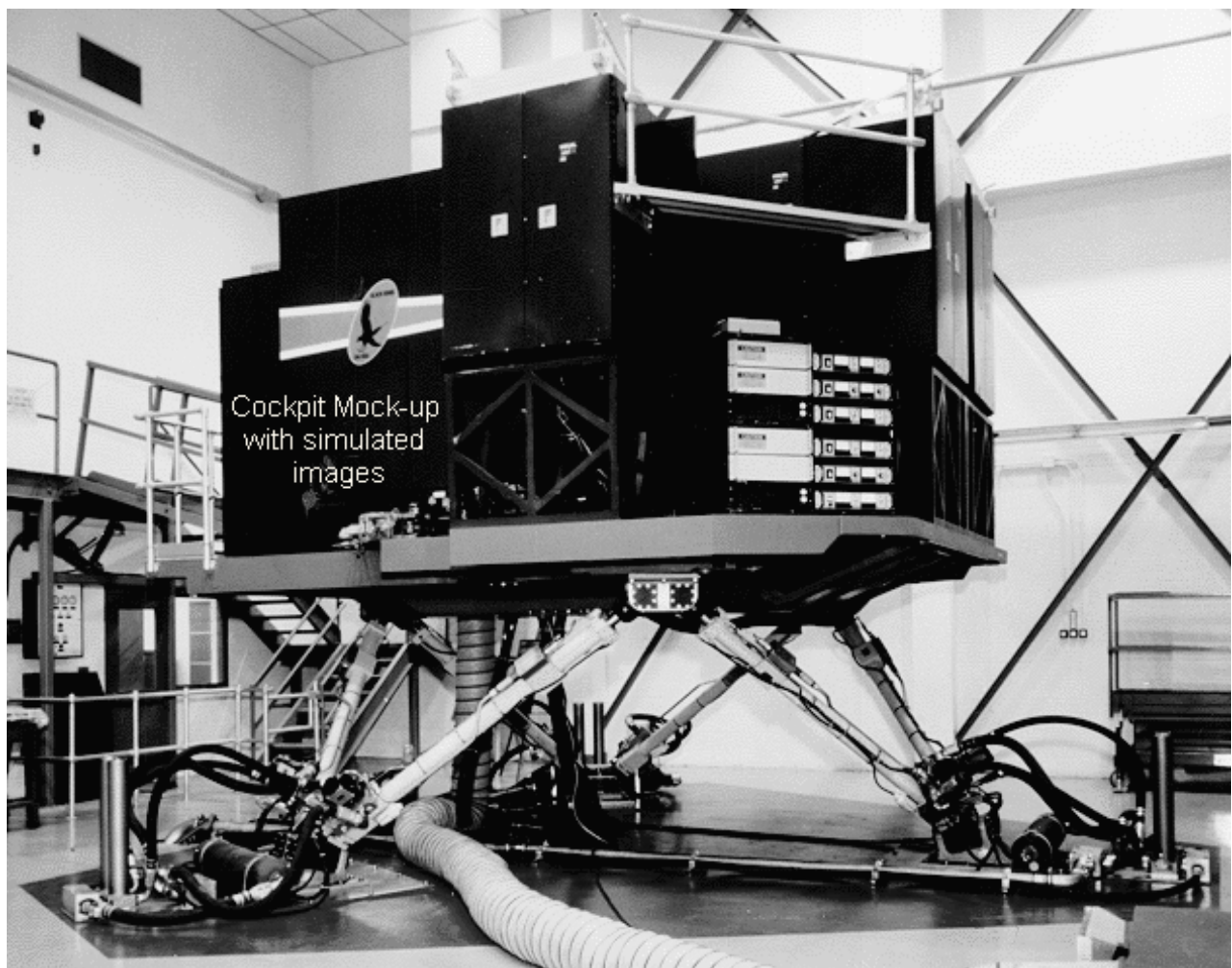

Figure 6-8. Flight Simulator

6-10.4 MISSION FLIGHT SIMULATORS

Mission flight simulators provide integration of air vehicle flight functions with mission equipment operation. As such, mission flight simulators should include accurate modeling and emulation of all subsystems in order to allow assessment of the proper achievement of mission functions, such as target engagement, in a fully simulated flight environment. Mission flight simulators should include the capability to conduct both air-to-ground and air-to-air missions. From such simulations early assessment of the impact of air vehicle handling and control characteristics on mission equipment performance, such as probability of hit or probability of kill, may be determined. Validation of a mission flight simulator is an extensive and time-consuming effort, which requires validation of all subsystem models including engine performance models, flight control law models, armament system fly-out models, etc.

6-10.5 BATTLE ENGAGEMENT SIMULATORS

Battle engagement simulators provide the added level of integration that comes from simulating the interactions of one or more friendly systems against one or more enemy systems. Such engagements might include air-to-ground, air-to-air, or ground-to-air situations. These engagements may occur simultaneously and with multiple air vehicle and ground force players. It is, therefore, important to assess the impact of parallel and sequential computations on the simulated results. Sequential computations can generally be accomplished more easily and at the least cost but may provide incorrect responses when multiple engagements are allowed. This combined arms battle may be controlled either semiautomatically or automatically by instructor personnel. Battle engagement simulators may include a network of several distributed mission simulators, as depicted in Fig. 6-9. High-level system parameters that go beyond traditional specification requirements may be assessed in this manner. These include loss exchange ratios and system exchange ratios.

Also the Defense Modeling and Simulation Office (DMSO) of the Advanced Research Projects Agency (ARPA) and the military services are in the processing of expanding the use of virtual prototypes. The battlefield distribution simulation-development (BDS-D) is an example of one development, which focuses on providing a war fighting assessment capability network using a soldier-in-the-loop virtual reality approach. See *Virtual Prototyping: Concept to Production* (Ref. 7) and *The Defense Modeling and Simulation Office(DMSO)* web site (Ref. 8).

6-11 SIMULATIONS AS SOFTWARE ENVIRONMENTS

Simulations can be used as part of the software engineering and test environments both without and in conjunction with actual system hardware. This paragraph describes simulation of the host, the host environment, the system environment, and embedded simulations. These simulations are often implemented using discrete event models.

6-11.1 HOST

The host is the processor that executes the subsystem or system software program. Often the host processor is simulated on a mainframe computer, which allows software development and system performance assessment prior to availability of the host processor hardware. The mainframe computer is programmed to simulate the planned host processor, and the simulation
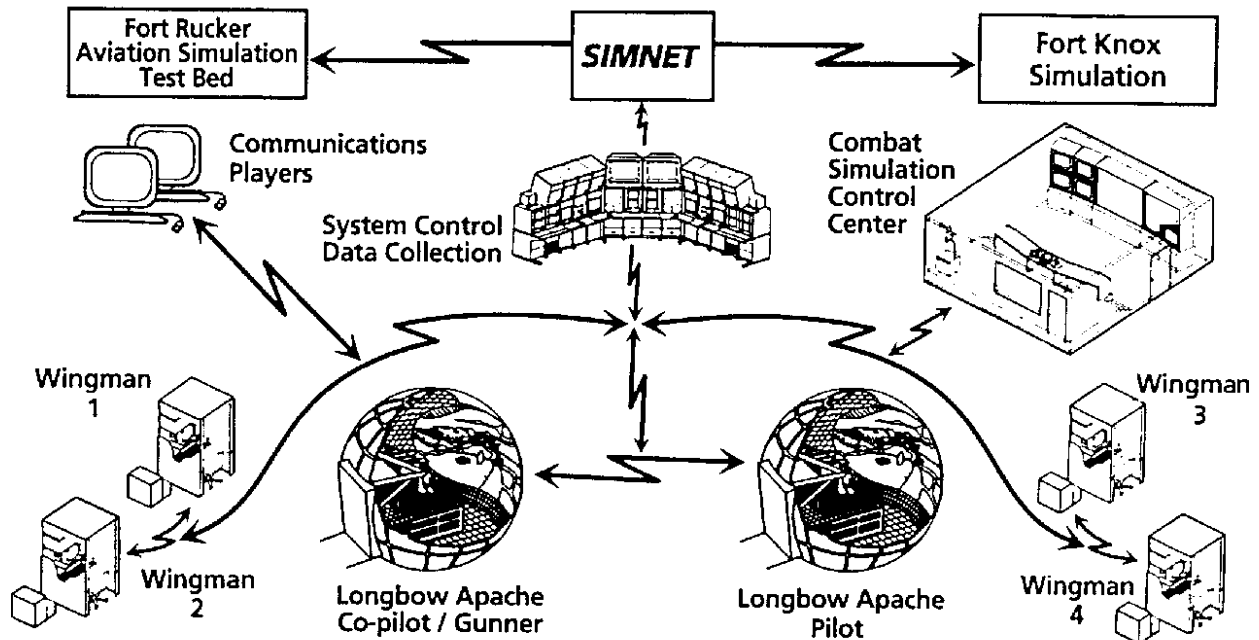
Figure 6-9. Battle Engagement Simulation

should allow assessment of throughput capacity, timing, and memory requirements. It also is useful because it provides interface compatibility with the host environment emulator. The simulation allows the user to display and modify simulation parameters, set breakpoints and control tracing, display simulation reports, perform simulation output analysis, and generate graphic displays at execution time. Queuing analysis techniques are often used in the simulation for the analysis of the host processor. The development of high-detail, large-scale simulation models can become very time-consuming to construct and maintain. When funds and schedule are limited, it may be more useful to develop small-scale models that allow high-level design decisions and would thus provide only preliminary preflight software qualification data.

6-11.2 HOST ENVIRONMENT

In addition to simulating the host processor, simulating the host environment may also be a useful development tool. The host environment includes all interface inputs and outputs, and the host environment simulation should replicate these interfaces and signal responses. These environment simulations may be used to test more than one host processor. The discussion in subpar. 6-11.1 concerning techniques, applicability, and qualification issues applies here as well.

6-11.3 SYSTEM ENVIRONMENT

System environment simulations are built from host simulations, host environment simulations, and operational environment simulations. (The intended host is the actual hardware that will ultimately execute the software in the air vehicle.) They allow assessment of the execution of software for the target architectures other than that of the host machines and thus

allow testing of software design implementation. When properly implemented and validated, they can provide information that supports preflight software qualification. However, full qualification requires flight test.

6-11.4 EMBEDDED SIMULATIONS

Simulations may also be embedded in an operational system to provide unique capabilities to the operator and maintainer. Simulations that provide a training capability for exercising system functions, such as weapons firing without actually doing so, enable economical maintenance of proficiency. Embedded simulations may also include trajectory predictors, heads-up display (HUD) images, and virtual cockpit displays. With these, based on artificial intelligence or neural network techniques, a pilot's associate could provide recommendations that allow the pilot to perform rapid simulation assessments in a high-threat environment. Special care must be taken during validation and qualification of embedded simulations to ensure system performance is not degraded with the addition of training simulations. Another consideration is to provide positive indications and safety interlocks to prevent inadvertent weapons activation while in the training mode.

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LIST OF ACRONYMS

AI	=	Artificial Intelligence
APU(s)	=	Auxiliary Power Units
CAE	=	Computer-Aided Engineering
CAM	=	Computer-Aided Manufacturing
CFD	=	Computational Fluid Dynamics
FOD	=	Foreign Object Damage
HISS	=	Helicopter Icing Spray System
HUD	=	Heads Up Display
IO	=	Input-Output
PFD	=	Powered Force Models
PFM	=	Powered Force Models
TDT	=	Transonic Dynamics Tunnel
DMSC	=	Defense Modeling and Simulation Office
ARPA	=	Advanced Research Agency
BDSD	=	Battlefield Distribution Simulation Development